RICHARDSON'S BLUEBOOK of PROJECTION

Seventh Edition

SUPPLEMENTED WITH
SOUND TROUBLE-SHOOTING CHARTS
ALPHABETICAL INDEX

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BLUEBOOK OF PROJECTION

Seventh Edition

SUPPLEMENTED WITH
SOUND TROUBLE-SHOOTING CHARTS,
ALPHABETICAL INDEX
and including an Introduction to
THEATRE TELEVISION

EDITED BY AARON NADELL

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PREFACE TO THE SEVENTH EDITION

The Bluebook of Projection is kept abreast of developments by being revised at suitable intervals.

In this Seventh Edition readers will find that all basic electrical data, which in previous editions appeared in various sections of the book, has been completely rewritten and brought together so as to constitute a continuous presentation, designed to facilitate study and reference both by the beginner to whom it may be completely new, and by the experienced projectionist who wishes to refresh his knowledge.

Many other portions of the Bluebook have been extensively rewritten (in accordance with policies followed in the past) to simplify still further the method of presentation, or to bring essential details up to date. New material has been added in substantial quantity covering equipment, methods or practices introduced to the industry since the last previous edition.

Further, a new chapter, dealing with television, has been introduced in the Seventh Edition, with a view to enabling readers to familiarize themselves in a broad way with the basic principles of that art, so they will not be caught completely by surprise if and when they are confronted with its practical apparatus, as so many projectionists were caught upon the introduction of sound.

The generous response which projectionists have given previous editions through so many years indicates that the volumes have been found useful. The author and publishers earnestly hope that projectionists and others interested in motion picture projection will find this Seventh Edition even more helpful.

F. H. Richardson.

Scarsdale, N. Y.
November 15, 1942.

CONTENTS

PAGE

PREFACE v

ACKNOWLEDGMENTS viii

DEDICATION ix

CHAPTER PAGE

I. INTRODUCTION OF ELECTRICAL ACTION 4

II. INTRODUCTION TO THE ACTION OF ALTERNATING CURRENT 28

III. PRACTICAL ELECTRICAL CALCULATIONS 41

IV. ELECTRICAL APPARATUS COMPONENTS 58

V LINE POWER SUPPLY CIRCUITS 99

VI. RECTIFIERS 109

VII. GENERATORS AND MOTORS 129

VIII. BATTERIES 163

IX. LENSES AND MIRRORS 178

X. SCREENS 225

XI. THE FILM 250

XII. THE MOTION PICTURE PROJECTOR 284

XIII THE PROJECTION ROOM 331

XIV. THE LIGHT SOURCE 361

XV. SOUND EQUIPMENT AND SOUND 417

XVI. RECORDING AND REPRODUCTION 426

XVII. THE A. C. TRANSMISSION LINE 432

XVIII. COMPONENT PARTS OF A SOUND SYSTEM 440

XIX. POWER SUPPLY FOR SOUND SYSTEMS 449

XX. SOURCES OF SOUND CURRENT 460

XXI. THEORY AND WIRING OF AMPLIFIERS 485

XXII. SPEAKERS 535

CONTENTS

Chapter Page

XXIII. Drives 550

XXIV. Control Tracks and Stereophonic Sound 576

XXV. The Operation of Sound Equipment 585

XXVI. Maintenance of Sound Equipment 603

XXVII. Television and Radio Components 624

XXVIII. Television and Radio Transmission 633

XXIX. Television and Radio Receivers 641

XXX. Some Television Details 650

Supplement: Sound Trouble-Shooting Charts 655

Index 703

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The author is also most grateful for particular aid or advice extended in connection with specific details by Henry Heidegger, John H. Hertner, A. H. Kopprasch, Leonard May, C. L. Stong and Harry Strong.

—F. H. R.

DEDICATION

To projectionists everywhere
and to all who have advanced the craft
of motion picture projection the
Bluebook of Projection
is gratefully dedicated
with the admonition that
no matter how perfect your work may be
there is always room for improvement.

PRINTED IN THE UNITED STATES OF AMERICA

INTRODUCTION TO ELECTRICAL ACTION

Practical Questions

(For answer to each question see statement of corresponding number in Chapter I)

1. What is the most important form of power used in the projection room?
2. What is the least that a projectionist must know about electrical action?
3. How much more should he know?
4. Why must today's projectionist understand modern theories of electrical phenomena?
5. What is considered to be the basis of all electrical action?
6. Is the electron smaller than the smallest atom of copper in a copper wire?
7. Are very many electrons needed to light a 100-watt lamp for one second?
8. Are electrons, as used in ordinary electrical work, both positive and negative?
9. Does the generation of electricity consist of the creation of electrons?
10. What is the difference between "free" and "atomic" electrons?
11. What must be done to produce a positive electrical charge?
12. Do electrons repel each other; why?
13. What word is used in measuring the strength of an electric charge?
14. Which does the projectionist use more often in his work, the electric charge or the electric current?

Electrical Charges and Voltage, page 7

15. Of what does an electric current consist, and in which direction does it flow?
16. Does an ampere of electricity consist of any specific number of electrons?
17. What is an ampere?
18. What must be provided to permit electric current to flow?
19. Is there any such thing as a perfect conductor of electricity?
20. Is there any such thing as a perfect non-conductor?
21. Name some conductors of very low resistance. Name some of very high resistance.

OHM'S LAW, PAGE 10

22. Are common electrical calculations involving voltage, current and resistance very difficult?
23. What governs the number of electrons that will pass per second (current) through any given conductor?
24. What governs the number of electrons that will pass per second (current) at any given voltage?
25. What two factors must be taken into account in calculating current strength?
26. Explain the terms ohm, ampere and volt.
27. Where both current and resistance are known, how can voltage be calculated?
28. How many amperes will 10 volts cause to flow through a resistance of 10 ohms?
29. Give the three formulas of Ohm's Law.

PRACTICAL D.C. CIRCUITS, PAGE 13

30. What is the simplest form in which electricity enters the projection room?
31. What is meant by saying that electric wires possess polarity?
32. Draw a simple schematic circuit of two common projection room wiring arrangements.
33. What happens when wires that terminate at an open switch are connected with a source of electrical power?
34. What happens when such wires are again disconnected from the source of power?
35. What happens when wires, connected to a source of electrical power, are bridged by a path through which electrons can move?
36. What is an electrical circuit and why is it so called?
37. Will current flow from the negative wire of one circuit to the positive wire of another and entirely independent circuit?
38. Will current flow if there is no return circuit to *its own* generator?
39. Will current other than a charging surge be wasted by ground connections?
40. What is a short-circuit?
41. What is a "ground"?
42. Under what conditions can a short circuit be a connection of *high* resistance?

ELECTRICAL POWER, PAGE 20

43. Are amperage and electrical power the same thing?
44. Is electrical power the same thing as voltage?

45. Does a current of 1 ampere through 10 ohms represent more power than a current of 1 ampere through 1 ohm?
46. If neither the volt nor the ampere be the word for electrical power, what word can be used for it?
47. How is the power of a d.c. circuit calculated?
48. Give a second formula for finding the power of a d.c. circuit.
49. Write the formulas of Questions 47 and 48, above, in abbreviated form.
50. When is the formula of Question 48, above, particularly useful?
51. Can the square root of a number be found without following the full process described in arithmetic books? By what method?
52. Explain the terms "square" and "square root."
53. Explain how a square root can be found by approximation and trial multiplications.
54. Are many trial multiplications needed to approximate a square root with sufficient accuracy?
55. Write "the square root of 26" in abbreviated form.

Magnetism, page 22

56. How can naturally magnetic iron ore be used to magnetize other pieces of iron or steel.
57. How can an electric current be used to magnetize pieces of iron or steel?
58. Does a wire carrying direct current possess the properties of an iron magnet?
59. Name two ways in which the power of an electro-magnet can be increased.
60. Name one way in which magnetic flux resembles an electric current.
61. Are efficient conductors of the electric current also efficient conductors for the magnetic flux?
62. Since electrons in motion, constituting an electric current, act as a magnet, and since every atom of material substance contains atomic electrons in motion about its center or core, must not every atom be a magnet?
63. If every molecule of iron is a magnet, should not every piece of iron be a magnet at all times.
64. Steel is harder to magnetize than iron, but retains its magnetism much longer. Can this be explained by the known differences between iron and steel?
65. What substances, aside from iron and steel, make useful magnets?

CHAPTER I.

INTRODUCTION TO ELECTRICAL ACTION

(1) All projection room machinery is driven by electricity. Electricity also provides the intense light that projects pictures to the screen, and actuates the apparatus which reproduces sound. Almost all the power—other than manual of course—that is used in the projection room for any purpose whatever is electrical power. Hence it is of vital importance that projectionists possess a rather complete knowledge of its nature and action.

(2) The least competent projectionist must know enough about electrical action to protect theatre patrons, property and himself against fire; to obtain satisfactory performance from the equipments under his charge, and to make simple repairs.

(3) Thoroughly competent projectionists do and should know very much more than the above. They know how to make their equipments deliver not merely passable results but the very best results of which each piece of apparatus is capable; how to assure maximum economy in operation; how to make even intricate repairs, at least on a temporary basis, and how to detect and understand warning signs of every description of trouble. They are able to plan and carry into effect adjustments necessary to prevent interruption in the performance, damage to equipment, or waste of electrical power. They are rightly held responsible for any deterioration in apparatus that might have been avoided, or at least minimized.

(4) Modern electrical apparatus can be thoroughly understood only on the basis of modern theories of the nature of electrical phenomena. In this seventh

edition of the Bluebook of Projection the modern conception of electricity is employed throughout. So long as projection room apparatus was restricted to motors, generators and lamps the newer and more complex understanding of electricity was merely interesting as a point of science; the older and simpler conception of electricity gave thoroughly satisfactory practical results. With the advent of sound, however, the older, simpler idea of electricity was not wholly adequate to explain some of the things that sound apparatus did, while the present approach of television makes a thorough understanding of modern concepts of current imperative. The newer understanding of electrical action is therefore employed, in this edition, from the very beginning.

ELECTRONS—THEIR SIZE AND ELECTRICAL POWER

(5) It is commonly agreed today that the basis of all electrical action lies in the activities and behavior of electrons, or, to put it another way, that electricity is granular in nature, consisting of small particles or grains called electrons.

(6) The electron is extremely small. Its size has been determined, but not its shape. It is assumed to be globular, with a diameter equal to 0.000,000,000,001,016 of an inch. It is worth noting that the smallest particle or atom of the copper wire through which electrons move as an electrical current is tens of thousands of times as large. .Hence if the copper atoms making up a wire be spaced at distances proportionate to their size, there is ample room for the smaller electrons to move between them.

(7) The weight of a single electron is interesting rather than important, being approximately 0.000,000,000,000,000,000,000,000,000,004 of an ounce. Some idea of the quantities of these tiny particles needed for the most ordinary electrical action may be gained by noting that 6 quintillions, 281 quadrillions of electrons per second are required for normal operation of an ordinary 100-watt lamp.

(8) As will be seen, it is of very great practical importance to remember that all electrons used in projection are "negative" in nature, and that any accumulation of them constitutes a negative electrical charge. In practical electrical work a positive charge never consists of an accumulation of positive electrons; only of an abnormal scarcity of negative ones. Although positive electrons are known to exist, and have been isolated, this may be done only with the help of very complex laboratory equipment; *never* by any ordinary electrical apparatus. So far as practical work is concerned there is no such thing as a positive electron. Throughout this book hereafter the word electron, wherever used, will mean a negative particle.

(9) In practice electricity consists of accumulations of electrons, either at rest or in motion. Methods for accumulating electrons into concentrations great enough to be useful in practical work will be discussed hereafter. At the moment it should merely be noted that every method of generating electricity involves only accumulating and concentrating electrons, not creating them. They exist everywhere.

(10) Electrons exist in two conditions, known as "free" and "atomic." Both are negative. Positive particles of various kinds also exist everywhere except in a complete vacuum. Negative electrons united with certain positive particles constitute atoms of material substances. An atom may be thought of as an apple hung in the air and surrounded by a cloud of flies; flies and apple together making up the single unit known as an atom. The apple (that is to say the core or nucleus of the atom), is positively charged; the flies are the negative atomic electrons. There may be few or many atomic electrons, according to the nature of the substance. In the case of an atom of hydrogen, there is only one electron. An atom of copper has 29; an iron atom, 26, an atom of lead, 82. Electrons can be temporarily

detached from their atoms, this being one way of concentrating them in "free" form to serve as electric current. But they also exist in free form (unconnected with any atom) throughout the universe.

ELECTRICAL CHARGES AND VOLTAGE

(11) Every material substance whatsoever is made up of atoms. All atoms consist of a positive core surrounded by negative electrons in sufficient numbers to effect a rough balance of the core's positive charge. Generally, material objects are in themselves substantially neutral, and do not under normal conditions exhibit an electrical charge of any kind. But if some of the atomic electrons, or some of the free electrons normally present, are removed from any material object, that object will be in the condition of being positively charged. As such it will attract negative electrons, or objects negatively charged. If electrons are added to a neutral object, either as an addition to its atoms or as an addition to its normal concentration of free electrons, the object will be negatively charged. In that condition it will be attracted to any positively charged object; also its surplus electrons will be attracted to a positive charge, and will move toward one if they can.

(12) Lastly, it should be noted that like charges repel each other; hence a concentration of electrons, however produced, will dissipate itself by force of mutual repulsion whenever the cause that produced the concentration is neutralized or removed. Insofar as they are free to move, the electrons will tend to spread themselves evenly throughout the universe.

(13) Electrical charges are measured in terms of volts, the definition of which will be given later. For the moment it will serve to note that high voltage naturally means a greater concentration or scarcity of electrons than does a low voltage. High voltage charges will exert greater attractive or repulsive force than low voltage charges.

ELECTRICAL MOTION AND CURRENT FLOW

(14) The form of electricity in which projectionists are most interested is not the charge (although they use electrical charges in their work) but the current, or flow of electrons from a point of high concentration to one of lower concentration. Most forms of electrical work are done by current flow; comparatively few practical results are produced by the mere presence of electrons in the form of charges.

(15) The *direction* of current flow is important in tracing many forms of projection room trouble. According to older theories, a "current," the nature of which was unknown, moved from positive to negative. It is now clearly understood, and universally agreed, that what really happens is that electrons move from places of high electron concentration (negative charge) to points of lower concentration, or of actual scarcity of electrons (points positively charged). In other words, electric current consists of a stream of electrons moving from negative to positive. Although agreement on this point is universal, the fact is not always expressed in unmistakable terms. Some authorities say that while electrons move from negative to positive, the "current" moves from positive to negative. In such cases the word current is used in an abstract or philosophical or mathematical sense, possibly with the thought in mind of avoiding a direct contradiction of older theories. A second apparent contradiction arises from the fact that men trained in older concepts of electrical action still, as a matter of mental habit, tend to trace through electrical wiring from positive to negative. The beginner will benefit if he concentrates on the accepted, undisputed fact that electrons move from negative to positive, and disregards (at least until he becomes more adept) any theories he may encounter about "the state of being positively charged" moving from positive to negative at the same time. This is true enough but confusing and

of no practical importance whatever. As for tracing through electrical wiring, it does not matter in the slightest whether a wire be traced from positive to negative or from negative to positive, as long as the direction of electron motion is kept clearly in mind.

(16) The strength of a current is measured in amperes. It is very important to remember that an ampere is *not* a specific number of electrons, but a rate of flow. This distinction is easily made plain by comparison with a current of water. Consider a pipe, and a pump causing water to circulate through the pipe. The flow may be at the rate of 1 gallon per minute or 10 gallons per minute. The actual number of gallons of water present in the pipe does not measure the current strength. Current strength is determined only by how many of those gallons of water pass a given point at a given time.

(17) Similarly in the case of electron current. The practical unit of electrical quantity (the "gallon," so to speak, of electricity) is the coulomb. The quantity of electricity equal to one coulomb is very approximately 6,281,000,000,000,000,000 electrons. One ampere, however, is the current strength represented by a flow of 6,281,000,000,000,000,000 electrons per second. If a coulomb of electricity were to pass through a wire in ½ second, the current strength would be 2 amperes. If the coulomb passed in 1/10th second the current strength would have been 10 amperes. Just as a current of water is measured in terms of gallons-per-second or gallons-per-minute, a current of electricity is measured in terms of coulombs-per-second; but in the case of electricity a more convenient term than coulombs-per-second has been provided in the word "ampere."

RESISTANCE TO ELECTRON MOTION

(18) Electrical current can flow only when switch and other connections are closed—that is, when a suitable path is provided for the electrons. Metals

constitute the best conducting paths, and of all the less expensive metals, the best is copper. The electrons cease to move when switches are opened because the air, which in that case intervenes between the switch points, does not provide a good path. In other words, it is not a good conductor.

(19) There is, however, only one conductor known that is perfect, or nearly perfect—that is a metal frozen to hundreds of degrees below zero, Fahrenheit. So far as has been determined such a conductor offers no resistance at all to the motion of electrons. The resistance of all metal conductors increases as their temperature rises. At very high temperatures it may become very great. Carbon, to the contrary, offers less resistance hot than cold. Under projection room conditions conductors of every nature offer some resistance; none are 100% efficient.

(20) Similarly, neither the air between switch blades, the rubber or bakelite used for insulation, or any other known substance, at any temperature, is a perfect non-conductor.

(21) Since in practice there is no such thing as a perfect conductor or a perfect non-conductor, it is accurate and helpful to consider that all substances, without exception, conduct the electric current, but that some are conductors of low resistance (metals, in particular) and some that offer very high resistance. Silver is the best conductor, copper and aluminum come next, iron offers so much resistance that iron wire is sometimes used as resistance wire to limit the amount of current flowing. Carbon is a conductor of medium resistance, sometimes used as a resistor; rubber, glass, oil, sulphur, bakelite, cotton, paper and ceramics offer extremely high resistance and are not used as conductors, but as insulators to prevent current from flowing.

OHM'S LAW

(22) It is of enormous practical importance that the projectionist understand the exact quantity of

current (number of amperes) that will flow under any stated conditions of voltage and resistance. Common electrical calculations involving current, voltage and resistance are extremely simple to a man who thoroughly understands the exact relationships involved. Where the electrical action involved is not clearly understood, even the application of the very simple arithmetical formula provided for the purpose of such calculations sometimes leads to confusion. It will therefore be helpful to consider voltage, current and resistance in a little more detail first.

(23) Note that when electrons are accumulated or concentrated, thus forming a negative charge, their mutual repulsion for each other will cause them to move outward from the point of concentration in all directions in which conducting paths are provided. The number of electrons that will move in one second through any given conductor will depend in part on the strength (voltage) of the charge that repels them. The greater the voltage of the charge, the stronger will be the repulsive force that causes them to move. If there is a positive charge at the far end of the conductor, this will serve as an attractive force. The stronger the positive voltage the stronger the attraction will be. In practice, the strength of a current depends in part not only upon the voltage repelling the electrons, but also on the positive voltage attracting them—that is, on the *voltage difference*, or as it is sometimes called, potential difference between the two ends of the conductor. The greater the voltage difference between two points, the greater will be the strength of the current flowing through a connecting conductor.

(24) But the resistance of the conductor also influences the current flow. For any given voltage difference, the greater the resistance of the conductor, the smaller will be the number of electrons able to pass through it per second.

(25) Hence, in calculating the current through any conductor it is necessary to take into account

both the voltage difference that causes electrons to flow and the resistance of the path which opposes their motion.

(26) Resistance is measured in ohms, one ohm being the amount of resistance offered by a column of mercury 1 sq. millimeter in cross-section and 106.3 centimeters long, at a temperature of 32° F. One ampere is the current which, passing through a solution of silver nitrate under certain specified conditions, will deposit or "plate out" 0.00111800 grams of silver per second. The historical and mathematical reasons behind the choice of these seemingly complex standards are of no practical importance. What matters most to the projectionist is that the unit in which the force of electrical charges is measured, the volt, is simply that potential difference which will cause one ampere to flow through a resistance of one ohm.

(27) Because one volt is that force which will make one ampere flow through one ohm, it is perfectly obvious that 2 volts will drive 2 amperes through 1 ohm—or 1 ampere through 2 ohms. Similarly, 2 volts will drive ½ ampere through 4 ohms. The relationship between volts, amperes and resistance is thus very simple. It can be expressed in the simplest kind of formula: Voltage = Current x Resistance. This is usually written as $E = I \times R$, or $E = IR$, in which E stands for voltage, electromotive force, the force that causes electricity to move, I for current as expressed in amperes and R for ohms resistance.

(28) The reader can readily understand that if 1 volt will drive 1 ampere through 1 ohm, 10 volts will drive 1 ampere through 10 ohms, 2 amperes through 5 ohms, or 5 amperes through 2 ohms. In every case the numerical value of the voltage equals amperes times ohms. The standard for the volt was defined thus to make this simple calculation possible.

(29) Moreover, the formula works in three ways, since if the resistance of a conductor is known to be

5 ohms, and the current flowing through it is known to be 2 amperes, the voltage must be $5 \times 2 = 10$ volts; but if the voltage is known to be 10 volts and the current to be 2 amperes, the resistance of the conductor must be $10 \div 2 = 5$ ohms; if the resistance were anything else the current would be greater or less than 2 amperes. The formula above given is with equal accuracy written as $R = \frac{E}{I}$. Similarly, when both resistance and voltage are known the amperage can be found, since it will always be that current which that particular voltage will drive through that resistance; the formula for finding the current value being $I = \frac{E}{R}$. All three forms of this formula constitute what is called Ohm's Law.

Every projectionist should memorize and know its three forms as well as he knows the spelling of his own name. He should be able to use them in electrical arithmetical calculations as easily as he counts change, since he will need to use Ohm's Law very frequently in his work. Unless he has it at his fingertips he will not be able to do the work expeditiously.

Practical D. C. Circuits

(30) The simplest form in which electricity enters the projection room is through the common two-wire, 110-volt d.c. circuit or "line." Physically, the line consists of two insulated wires which, after being serviced by suitable fuses, terminate at a double-bladed switch. To the opposite end of the switch two insulated wires are attached, which receive the current when the switch is closed, conveying it to various circuits where its use is required.

(31) Electrically, the incoming wires possess "polarity." That is to say, one is positive, the other negative, according to their connection with the

positive and negative terminals of the power house generator. The generator, sucking free electrons out of one wire to accumulate them in the other, charges the wires at positive and negative polarities, respectively. The switch point connected with each wire will of course be charged at the same polarity as the wire itself.

(32) Fig. 1 shows two simple and common wiring arrangements through which a projection room may be supplied with current for light and power. The top pair of wires pass through switch A, thence through fuses to Switch B, beyond which they supply current to row a lamps. The lower pair of wires after passing through Switch A and its fuses, continue through motor fuses to a d.c. motor. Both lines originate at a "power source," which may be a distributing switchboard in the projection room, or the meter board in the basement of the theatre In both cases the ultimate origin of the electricity in the lines is, of course, the generator in the distant power house.

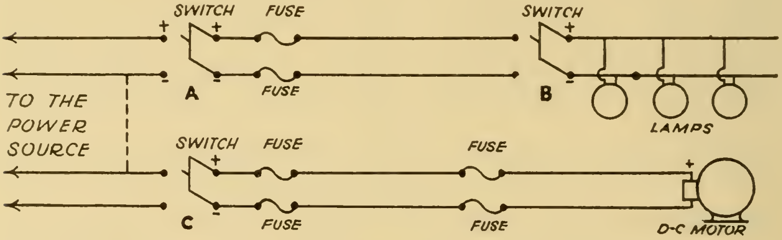


FIGURE 1

(33) In the upper circuit as drawn, the top point of Switch A is at positive polarity, and the bottom point at negative polarity; that is, the lower point of Switch A carries a surplus of electrons while there is an abnormal scarcity of them on the upper point. If this is a 110-volt circuit, the difference in electron concentration, charge or potential as between the two points is equal to 110 volts, or to an electromotive force capable of causing 1 ampere to flow through

a resistance of 110 ohms. While the circuit remains in the condition shown in the drawing, the blades of Switch A carry no charge or potential of any kind, since they are insulated from the source of power by the air which separates them from the points of the switch. If Switch A be closed, its blades immediately become charged at the same polarity and voltage as the points with which they are in electrical contact; the fuses and the wires extending to the points of Switch B become similarly charged. For the charge to be extended to Switch B's points requires a momentary flow of current through the connecting fuses and lines; a very brief surge during which electrons move to the lower point of Switch B and are drawn off from the upper point of that switch. This brief flow of "charging current" having taken place there is no further electron motion, except the trifling flow, too small to be easily measured, which results from the continued leakage through the air and insulation.

(34) If, now, Switch A be reopened, the charge that was imparted to the points of Switch B is lost very quickly, "leaking off" through the insulation until the electron concentration at both blades of the switch is the same. This action is almost instantaneous, so that the points of Switch B are for all practical purposes "dead" the instant Switch A is opened. (If Switch B were a condenser, an electrical device explained on a later page, it might hold its charge for a considerable length of time after Switch A was opened, and shock anyone who touched it without taking proper precautions.)

(35) If both Switch A and Switch B be closed, the charge (difference of polarity or voltage) extends to the lamps, and since there is in each lamp a filament through which electrons can move, a flow of current will result, electrons passing from the negative wire through the filaments to the positive wire. The amount of current flowing will depend on the effective resistance offered by the filaments and

can be calculated in accordance with Ohm's Law, if the filament resistance be known; or that resistance can be determined by measuring the voltage and the amperage and using the formula $\frac{E}{I} = R$.

(36) The electrons, having reached the upper wire, flow back to the positive terminal of the generator in the power house, where they are again collected by generator action and deposited on the negative generator terminal, and so return to go through the lamps again. They continue to go round and round as long as the switches remain closed. Hence the electrical arrangement through which current flows is called a circuit. There are two circuits in Fig. 1; the upper or lamp circuit, which includes Switches A and B, and the lower or motor circuit including Switch C.

(37) One very important practical point is that the negative polarity of any independent circuit does **not** send current to the positive side of any other independent circuit. Suppose that the two circuits of Fig. 1 each have separate, independent generators at the power house, and are not connected with each other in any way. Let the dotted line toward the left of Fig. 1 represent a connecting wire added, as shown, between the negative point of Switch A and the positive point of Switch C. It seems logical to suppose that electrons will flow from negative to positive, from a point where they are concentrated to a point where they are scarce. Their own mutual repulsion would force them to do this. As a matter of fact, when the connection represented by the dotted line is installed, only a brief charging current flows, in exactly the same way as a charging current flows to Switch B when Switch A is closed. The reason is made clear in the text dealing with Fig. 2.

(38) Fig. 2 is a simplified version of Fig. 1, but with the powerhouse generators included. If the connection represented by the dotted line be made, it is

clear that electrons from the negative wire of the upper generator could move to the positive wire of the lower generator, through the lower generator to the negative point of Switch C— and no further. There is no circuit through which those electrons could return to the positive terminal of the upper generator, hence no way they can keep going round and round. Under these circumstances the only current that could possibly flow would be, as said, a momentary charging current or surge to charge the circuiting wire, which is of no practical importance whatever. The same would be true even if all the switches of Fig. 2 were closed. The fact that the upper generator might be working at much higher voltage than the lower generator would also make no difference. Hence, it is often said that the positive polarity of one circuit and the negative polarity of another independent circuit have no attraction for each other. That is not strictly true, since opposite charges always attract, but while the two lines remain otherwise independent of each other, a connection from the positive of one to the negative of the other does not constitute a closed circuit, as Fig. 2 plainly shows. A charging surge of no practical importance is the only current that can flow through such a connection.

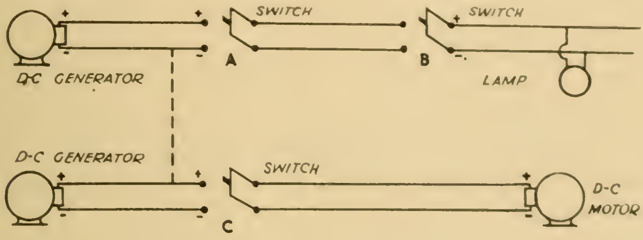


FIGURE 2

(39) A connection of the kind shown in Fig. 2 is seldom made in practice, but its electrical equivalent often exists in the form of ground or earth contacts.

Suppose that the negative side of the upper circuit of Fig. 2 and the positive side of the lower circuit of that diagram were grounded to earth; the dotted line would then represent the earth conductivity. The electrical condition would exactly duplicate that shown in Figs. 1 and 2, nevertheless there would be no waste in the form of an "earth" current. Only a charging surge flows through ground, and that only when the connection is first put in, or the generators first start operation. However, if one generator should gain or lose voltage with reference to the other, proportionate equalizing surges, still of no practical importance, would pass through the dotted line connection.

(40) A very different state of affairs exists if a connection like the dotted line of Figs. 1 and 2 is installed on circuits where the two generators are not completely independent of each other, or in cases where there is only one generator supplying both lines. Such an arrangement is shown in Fig. 3. Note

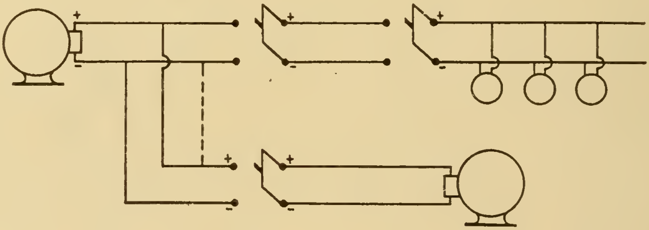


FIGURE 3

that in that diagram electrons from the negative side of the generator can move down the dotted line, and then back upward through the next line to the left until they reach the positive side of the generator, thence proceeding through the generator to its negative terminal and so going round and round. In such cases the generator is said to be "short-circuited," because the electrons have a short-cut path through which they can continue to move without encountering apparatus in which they meet appreciable resistance. But the less the resistance of a circuit, the greater the current which a given voltage will be able to drive through that circuit. The current in the short-circuit of Fig. 3, which encounters no resistance at all except that of the copper wires, would almost certainly be too strong for the wires or for the generator, and would burn out one or the other, except for protective devices as explained hereafter.

(41) The words short-circuit and ground are often used interchangeably, and a short-circuit such as that of Fig. 3 is often described as a "ground" even when no earth connection is involved. It is obvious, of course, that the condition in that diagram would be most likely to occur in practice through a mistake in making earth connections. If by error the positive instead of the negative side of the motor were grounded to earth, while either the lamp circuit or the generator were grounded at its negative terminal, the conductivity of the earth would supply the place of the dotted line of Fig. 3, with more or less disastrous results. The protection given by fuses in such cases is discussed elsewhere.

(42) A short-circuit is always a relative condition. In the case of Fig. 3 both the lamps and the motor have somewhat low resistance, no more than a few ohms. They can be short-circuited effectively only by some conductor of still lower resistance, namely, a copper wire or a good connection through earth. But many circuits used in the projection room have very high resistance; in some cases resistances as high as millions of ohms. Such a circuit could be "shorted" very effectively by a resistance of 10,000 ohms; where in the case of Fig. 3, if the dotted line represented 10,000 ohms it would have no more practical effect than if it were an open switch. A short circuit is always a connection of less resistance than the normal circuit. A high resistance connection can

form a very harmful "short" provided the resistance of the normal line is still higher.

ELECTRICAL POWER

(43) The power that can be obtained from an electric current is not a matter of current strength alone, as can easily be understood by considering a current of water. Imagine a waterfall flowing 100 gallons per second from a height of 10 feet, and another fall of exactly the same volume, coming from a height of 100 feet. Obviously the second waterfall will be able to deliver 10 times as much power as the first; if its height were 200 feet it could deliver 20 times as much power. The power is clearly not a matter of current flow alone, but of pressure also, which in the case of a waterfall is height; in the case of electricity is voltage.

(44) On the other hand, consider two waterfalls of the same height, but one flowing at the rate of 1,000 gallons per second while the other is a mere trickle. The fact that the height is the same in both cases will not give both falls the same power.

(45) Similarly in electricity. A flow of 1 ampere driven by 1 volt through 1 ohm does not have the power of a flow of 1 ampere driven by 10 volts to overcome the resistance of 10 ohms. The latter has 10 times the power of the former.

(46) Electrical power is measured in watts. It is not amperage alone, nor voltage alone, but both.

(47) In a d.c. circuit, power is found by multiplying the voltage by the amperage—1 volt x 1 ampere = 1 watt, or I x E = W.

(48) In practice it is sometimes highly convenient to use a somewhat different formula for finding power, or wattage. By Ohm's Law, I x R = E. Translating from arithmetic into English, E, and I x R, are exactly the same thing—equal to each other—so that in any formula whatever one could be substituted for the other with perfect accuracy. In the

formula for finding power—just given (I x E = W), E can be eliminated and I x R substituted, since I x R and E are one and the same. The formula for power therefore can be written I x I x R = W, which is exactly the same thing as saying I x E = W. Both formulas for power are equally accurate, both are used in common practice, choice between them is merely a question of which happens to be the more convenient in a given problem.

(49) Just as I x E is sometimes written IE, with the sign x omitted for the sake of brevity, so the formula I x I x R is sometimes written I^2R (pronounced I square R), making this formula for power read: $I^2R = W$.

(50) That formula is particularly useful where only the resistance and the wattage are known. In such cases complete information about the circuit can be obtained by solving the formula for I and then (with both I and R known) applying Ohm's Law to find the voltage. Thus, suppose the resistance to be 4 ohms and the power 16 watts, the formula become $I^2 \times 4 = 16$. I^2 obviously equals 4, the square root of which is 2. By Ohm's Law 2 amperes through 4 ohms equals 8 volts; and, double-checking by applying the other formula for d.c. power, 8 volts x 2 amperes = 16 watts.

(51) The function of the Bluebook of Projection is not to review the arithmetic every reader learned at school. Those who have forgotten how to use fractions should review that knowledge. Those who have forgotten how to calculate square root, however, will not find it absolutely necessary to learn that process over again. In projection practice it is needed only occasionally, and on such occasions the projectionist can use the short-cut method of approximation. All he need remember is what a square root is.

(52) Since 2 x 2 = 4, 4 is the square of 2, and 2 is the square root of 4. Similarly, 9 x 9 = 81; 81 is the square of 9, 9 is the square *root* of 81. It is entire-

ly accurate to write 81 as 9^2, just as 4 can be written 2^2. The square root of 100 is that number of which 100 is the square—in this case, 10. Nothing else need be remembered.

(53) Suppose it becomes necessary to take the square root of 175, and the proper process has been forgotten. A glance will show that it must be greater than 10, since 10 x 10 = 100. On the other hand, the square root of 175 must be less than 20, since 20 x 20 = 400. The number desired therefore is larger than 10 but smaller than 20. It is nearer to 10 than to 20, since 175 is nearer to 100 than to 400. A trial attempt may be made with 13. This results in 13 x 13 = 169, which is too small. Trying 14 gives 14 x 14 ÷ 196. The required square root, (that of 175) therefore must be larger than 13 but smaller than 14—in other words, 13 plus some fraction. One or two more trial multiplications will show that 13.3 x 13.3 gives 176.89, which is near enough for all practical projection room purposes.

(54) The projectionist need never hesitate to use the power formula, $I^2R = W$, because working it out involves figuring a square root. He doesn't have to figure a square root. He can always approximate it with sufficient accuracy by a few trial multiplications.

(55) The sign $\sqrt{\ }$ means "take the square root of." The phrase, "the square root of 175" is more conveniently written as $\sqrt{175}$.

Magnetism

(56) Certain iron ores naturally possess magnetic properties; a piece of such ore is a magnet just as it comes from the mine, needing no treatment, as other forms of iron do, to make it a magnet. Pieces of such ore dangling from a bit of string which left them free to turn were the first magnets by which ships were steered. Refined iron or steel is not normally magnetic, but can be magnetized in several ways, one of

which is to place a piece of iron close to a piece of magnetic ore. The iron becomes magnetized by virtue of the fact that it has been placed in a magnetic "field." It loses its magnetic power when it is removed from the field. A piece of steel is more difficult to magnetize than a similar piece of iron, but when removed from the field it remains a magnet. It can be used to magnetize other pieces or iron or steel, just as the original ore was.

(57) Iron and steel can also be magnetized by placing them close to an electrical conductor carrying direct current. Steel magnets are manufactured by placing them inside a coil of wire carrying direct current. Projectionists often magnetize steel screwdrivers and other tools by winding some turns of soft, insulated wire around the tool and connecting the ends of the wire with a battery or other source of d.c. The magnetized screwdriver or hammer are useful because they attract small iron screws, bolts, etc., preventing such objects from becoming lost.

(58) The wire carrying current acts in the same way as the magnetic ore or magnetized steel, both in magnetizing iron and steel objects brought within its field and in attracting small, light pieces of those metals. In short, a wire carrying current is a magnet —an electro-magnet—as long as the current continues to flow. It attracts the needle of the magnetic compass, and in other ways acts like a magnet made of steel or iron.

(59) The power of an electro-magnet can be increased by bunching a long length of wire in a small area; this is done by winding the wire in the form of a coil. The magnetic force can also be increased by increasing the amperage in the wire. Hence, electro-magnets are sometimes rated in "ampere-turns," that is, the amperage flowing multiplied by the number of turns of wire in the coil.

(60) The magnetic force, which acts upon objects located at some distance from the magnet, is called a flux, and conveniently measured in terms of "lines

of force." The stronger the magnetic flux, the greater the number of lines of force said to exist. The nature of the flux is quite unknown, but in one way it may be thought of as analagous to an electric current, since it travels better through some conductors than through others.

(61) Iron, or other material capable of being magnetized, is the most efficient conductor for magnetic flux. Copper, which is better than iron as a conductor of electricity, is a poor conductor of magnetism. Electro-magnetic devices of many kinds are used in the projection room, as will be seen. Those in which the efficiency of the magnetic action are important are usually built with cores of iron or other magnetic material, about which the electro-magnetic coil is wound. Such a core is of course instantly magnetized, and its iron magnetism (ferro-magnetism) reinforces the electro-magnetism of the coil.

(62) The fact that wires carrying current act as magnets indicates that magnetism is a property exhibited by electrons in motion. Every atom of material substance contains electrons which revolve about the positive center of the atom as the earth and planets revolve about the sun. It follows that every such electron is a small magnet. Most atoms, however, contain more than one "planetary" or atomic electron. They do not all move in the same direction at the same time. Magnetic flux set up by one atomic electron may be opposed and neutralized by the opposite flux set up by an electron revolving in the reverse direction. Even where the majority of electrons in an atom are moving in the same direction, the atom is generally combined in a molecule with other atoms. Many types of molecules exhibit weak magnetic properties, so weak, however, that laboratory equipment is needed to detect them.

(63) All iron molecules are naturally magnets, but in any unmagnetized piece of iron the molecules are pointed or oriented so that the magnetic flux of one molecule is cancelled by that of a neighbor and ex-

ternally the piece of iron does not exhibit magnetic properties. However, when that iron is placed in a magnetic field, the attraction of the field lines up the molecules, twisting them around so that the piece of iron as a whole becomes a magnet. When the influence of the external field is withdrawn, the molecules twist back to positions in which the iron appears to be "demagnetized."

(64) Steel consists of iron molecules held in a thin cement of carbon, silicon or other material. Steel is not magnetized as easily as iron, since the molecules or iron in the steel are less free to re-orient themselves in response to an external magnetic force. However, when steel once has been magnetized, and the external magnetizing force is than removed, the molecules also do not find it easy to swing back into their former "non-magnetic" positions. A piece of "hard" steel, properly magnetized, will remain a magnet for many years, while soft iron will demagnetize in a fraction of a second.

(65) Common today are special alloys or mixtures of metals which exhibit stronger magnetic properties than the best steel, or which magnetize and demagnetize more rapidly than the softest iron. Among the latter is permalloy—trade name for a substance used in the projection room, and elsewhere as a core for certain types of electro-magnetic devices which must be able to magnetize and demagnetize a great many times per second. A large number of alloys that make better magnets than the best steel are in common use. serving for example as the polarizing pieces of theatre loud speakers. The commonest alloys of this type combine large percentages of nickel and aluminum with iron, and at least one is said to contain no iron at all.

INTRODUCTION TO THE ACTION OF ALTERNATING CURRENT

Practical Questions

(For answer to each question see statement of corresponding number in Chapter II)

1. Do output terminals of a d.c. generator always have the same polarity?
2. Do output terminals of an a.c. generator always have the same polarity?
3. What is an alternation?
4. What is a cycle?
5. What types of alternating current are used in common a.c. power supply?
6. What frequencies of a.c. may be generated in the projection room?
7. Are 25, 50, 60-cycle currents low, medium or high frequencies?
8. What band of frequencies is utilized in sound apparatus?
9. What frequencies are used by theatre television apparatus?
10. Does the presence of a.c. mean that every electron moves from one end of the circuit to the other end?
11. Does the formula, IR = E, apply to a.c. circuits, or the formula, IR = Z?
12. During what moments does the formula IR = E fail to describe the true state of affairs in a d.c. circuit?
13. If an a.c. circuit includes a magnetic winding, does that circuit at any time obey Ohm's Law for d.c.?
14. For what purpose are henries used in connection with electrical measurement?
15. For what purpose are farads used in connection with electrical measurement?
16. If alternating voltage be applied to an a.c. circuit will a weak current flow in spite of the fact that the circuit is open?
17. Can a condenser give a.c. the effect of passing through insulation?
18. If the capacitance of a condenser be made greater, will its reactance increase or decline?
19. Give the letter abbreviations for inductive and capacitative reactance.
20. Is reactance the same at all frequencies? Explain.

21. What are the formulas for finding inductive and capacitative reactance?
22. What is the formula for impedance?
23. Can an electrical replacement be ordered accurately simply by designating the impedance of the part desired without reference to the frequency at which it is rated?
24. Is Ohm's Law for d.c. ever used in tracing trouble in a.c. circuits?

PULSATING D. C. AND OTHER COMPLEX CURRENTS, PAGE 34

25. Show how the behavior of simple alternating current can be diagramed in convenient form.
26. If two different currents are made to flow in the same wire, is the result made up of both currents?
27. What is an electrical component? Resultant?
28. Is any d.c., except that drawn from batteries, completely free from ripple?
29. Can components of a.c. or of fluctuating d.c. be isolated?

PHASE, PAGE 37

30. In an a.c. circuit containing a magnetic winding, do the alternations of current keep exact step with the alternations of voltage?
31. In such a circuit, does the current lag behind the voltage, or the voltage behind the current?
32. In a circuit containing only capacitance, would current and voltage be in phase with each other?
33. In an a.c. circuit containing only resistance, would current and voltage be in phase with each other?
34. What is the formula for power in an a.c. circuit?

CHAPTER II.

INTRODUCTION TO THE ACTION OF ALTERNATING CURRENT

(1) The function of an electrical generator is to create the condition of polarity at its output terminals, accumulating electrons at its negative output post and creating a scarcity of them at its positive output terminal. In a d.c. generator, one output binding post is always made negative by the action of the generator, the other is always positive, and electrons flow from negative to positive through any external circuit which may be connected with those terminals.

(2) The a.c. generator, however, produces an alternating polarity at its output terminals; the same output post is made alternately negative and positive; and the current through the external conductor periodically reverses its direction of flow in accordance with these reversals of generator output polarity.

(3) A single reversal of polarity is called an alternation. One alternation takes place when the terminal that was positive becomes negative while the terminal that had been negative becomes positive.

(4) A double alternation is called a cycle. A cycle is completed when one terminal has been negative, has become positive, and returned again to negative—or vice versa.

(5) Alternating currents are described in terms of cycles. The common power supply to the projection room in the eastern United States usually is 60-cycle. In the western part of the United States 50-cycle current is more commonly supplied, while 25-cycle or other types of supply are found in a few industrial areas.

(6) Alternating currents generated within the projection room by electrical or mechanical-electrical apparatus may range in frequency from 9 to 80,000,000

cycles per second. The terms low, medium and high frequency are commonly applied, but they are used in different ways.

(7) So far as common lighting and power circuits are concerned, there is usually one frequency—that at which power is supplied to the projection room. This is neither low, medium nor high, but is sometimes spoken of as the power frequency.

(8) Sound apparatus generates and utilizes a band of frequencies ranging from about 40 to about 9,000 cycles per second. From 40 to about 200 or 300 cycles are spoken of as "low" frequencies; 200 to about 3,000 constitute the medium frequencies; frequencies from 3,000 to 9,000, but more especially those above 6,000, are loosely spoken of as "high." All frequencies in this group (from 40 to 9,000 cycles) are also called "audio" or sound frequencies.

(9) Television apparatus uses audio frequencies. It also has signal frequencies, scanning frequencies, radio frequencies, video frequencies and ultra-frequencies. Signal and scanning frequencies range from a few hundred cycles per second to a few thousand cycles per second; radio frequencies are those up to several million cycles per second; video frequencies run to several hundred thousand cycles per second; ultra frequencies up to 80 million cycles per second. Intermediate frequencies, as the term is applied to apparatus for receiving radio sound, either alone or in association with a television program, cover frequencies of about half a million cycles per second. Intermediate frequencies in short-wave radio and in television reception are of several million cycles per second. The reader need not memorize these distinctions now. They will automatically become clear to him when he reads the sections of this book devoted to sound, television and theatre radio.

(10) In a.c. conductors the electrons need not flow completely around the circuit from negative to positive; the current tends to consist, rather, of an oscillatory to-and-fro motion of the electrons in the wires as each end of the circuit becomes alternately negative and positive.

(11) In direct circuits the current strength is determined strictly by the resistance and the voltage applied, according to Ohm's Law, but with a.c. the resistance of the conductor is not the only factor tending to oppose and limit the flow of current. Hence, Ohm's Law does not have the same form for a.c. as for d.c. The form of Ohm's Law for a.c. is $IR = Z$, in which Z stands for impedance. The resistance of the conducting path, R, is one factor, but only one, in the complex of opposing forces that go to make up Z.

(12) One of the factors involved in Z, or impedance, is magnetism. Magnetism is also an effect manifested by direct currents, as has been seen. Ohm's Law is not strictly true during the instant when direct current is turned on, nor at the moment when it is cut off. There is a very brief interval of time, while a magnetic field is building up around the wires, when the current does not reach the full strength required by the voltage and resistance of the circuit. The appearance of normal current, as called for by Ohm's Law, lags momentarily behind the application of the voltage. But when the magnetic field is once established, the relations indicated by Ohm's Law obtain, and continue to exist (unless the magnetic field is disturbed) until the current is switched off. When this happens the field is said to "collapse about" the wire, and in doing so generates a sudden surge of current stronger than that called for by Ohm's Law. In d.c. circuits that contain magnetic elements (for example, circuits that supply the "field" windings of loud speakers) opening of the switch is accompanied by a surge of current which flashes across the partially-opened contacts, often melting the edges of the switch blades and studs. For this reason spring-operated switches, that open very rapidly when their handle is operated, are used in such circuits. During the instant the switch is opening the current is momentarily greater than Ohm's Law specifies.

(13) In an a.c. circuit the current is continually increasing and decreasing, rising to a maximum in one direction, dropping off to zero, rising to maximum in the opposite direction, and so on, scores or hundreds or thou-

sands or millions of times per second. It is obvious that if an a.c. circuit includes a magnetic winding, the conditions just described exist constantly in and are normally part of the a.c. circuit action; so that the current never at any time obeys Ohm's Law for d.c. Ohm's Law for a.c. must allow for magnetic effects, known as inductance, or as inductive reactance.

(14) Inductive reactance retards the current at times when the voltage is increasing, and generates a reinforcing surge of current after the voltage has begun to decline, but its overall effect is to reduce the total current strength. Reactance, like resistance, limits the amount of current a given voltage can force through a circuit. Inductive reactance is measured in "henries", and is designated by the letter L.

(15) A second force operating to reduce the flow of alternating current is capacitative reactance, measured in farads or microfarads and designated by the letter C. In a sense, however, capacitance may be said to help the flow of current, since under certain conditions it makes it possible for the current to give the appearance and effect of flowing through an insulator.

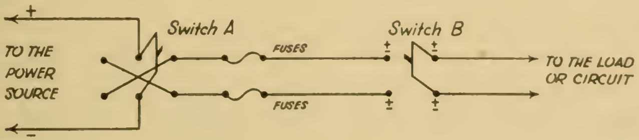


FIGURE 4

(16) Refer to Fig. 4, and compare it with Fig. 1. In Fig. 4 Switch A is connected as a polarity-reversing switch—a simple arrangement often used in practice. It is clear that if Switch A be closed to the left, the bottom stud of Switch B will be at positive polarity, whereas if Switch A be thrown to the right, the top stud of Switch B will be positive, and Switch B's bottom stud will be negative. If Switch A be closed first to left, then to right, then to left, and so on, an alternating voltage will appear upon the terminals of Switch B. And each time the

switch is thrown over (at each alternation) a weak charge-discharge current will flow through the fuses, in spite of the fact that Switch B is open. In other words, a weak alternating current, a charge-discharge current, flows in an a.c. circuit in spite of the fact that the circuit is open—in this case, open at Switch B.

(17) An electrical condenser is a device which possesses special ability to absorb electrical charges. In its simplest form it may be thought of as a sheet of glass, with sheets of tinfoil pasted to either side. The two sheets of foil are insulated from each other by the glass and do not touch each other at any point. A wire runs from each sheet of foil. If such a device were substituted for the points of Switch B, in Fig. 4, the charge-discharge current just referred to would be greatly increased. Making the glass thinner, or increasing the area of the sheets of foil, or substituting more efficient "dielectric materials" in place of glass, all would serve still further to increase the capacitance of the condenser. With a condenser of large capacitance substituted for the switch points of Switch B, appreciable alternating current would flow through the fuses of that illustration as long as Switch A were manipulated from left to right and back again to create an *alternating* voltage. But of course if Switch A were left in either position, producing only a direct voltage, a single flow of charging current through the fuses would end all further electrical activity. In view of these facts it is sometimes said that a condenser, in spite of the insulation separating its foil sheets or plates, "conducts" alternating current. What it really does, as explained, is permit the flow of a substantial charge-discharge current which amounts in effect and results to somewhat the same thing as if a.c. were actually passing through the insulation.

(18) The electrical condenser is therefore treated arithmetically as if it were a conductor possessing reactance. A condenser of very small capacitance has high reactance, a condenser of large capacitance has low reactance.

(19) Reactance is designated by the letter X. To dis-

tinguish between capacitative reactance resulting from the presence in the circuit of condensers, and inductive reactance resulting from magnetic elements, it is customary to use subscripts: X_C representing capacitative reactance, and X_L, inductive reactance. These symbols are pronounced: X-sub-C and X-sub-L.

(20) Reactance is not the same at all frequencies, of course. An inductive winding offers more reactance to a.c. than to d.c., more to a.c. of high frequency than to a.c. of lower frequency. A condenser, offering the full resistance of its insulating material to d.c., permits what is in effect a flow of a.c. through its insulation, and the higher the frequency, the better "conductor" the condenser will be. Put another way: an inductance conducts d.c. very well, low frequency a.c. poorly, high frequency a.c. not at all. A condenser conducts high frequency a.c. quite well, low frequency a.c. less well, and d.c. not at all.

(21) The reactance of a given inductance is determined by the formula: $X_L = 6.28 \times F \times L$; that is, X_L is equal to the inductance of the coil in henries, multiplied by the frequency of the current involved, multiplied by 6.28. The reactance of a condenser is found by the formula: $X_C = \dfrac{1}{6.28 \times F \times C}$. (In this formula C stands for capacitance in farads, whereas condensers are usually rated in microfarads or micro-micro-farads, that is, millionths, or millionths of a millionth, of a farad).

(22) When inductive and capacitative reactances are known, it becomes possible to find the impedance of a circuit: $Z = \sqrt{r^2 + (X_L - X_C)^2}$.

(23) Only very rarely, in tracing certain forms of trouble, will the projectionist have occasion to use any of these formulas, but he should at all times have a fair idea of the meaning of reactance and of Ohm's Law for a.c. In particular, it is important to remember that *frequency* is one of the factors that determine reactance, and reactance is one of the components of impedance, so that in practice it is possible to cite the impedance of a part or a circuit only with reference to some stated frequency of

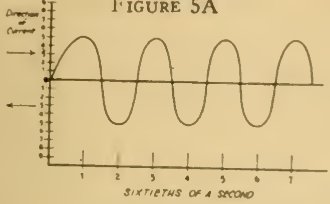
current. The impedance will be different at all other frequencies. Apparatus and circuits used for the reproduction of sound are required, as has been said, to deal not with one frequency but with a band of frequencies, ranging from 40 cycles to 9,000 cycles. The impedance of parts and circuits is usually given with reference to some one frequency, such as 600 cycles or 1,000 cycles. Consequently, in ordering a replacement part which should have a certain impedance, it is important to note the frequency at which its impedance is rated. A coil having an impedance of 200 ohms at 600 cycles will not be an accurate replacement for a coil having 200 ohms impedance at 1,000 cycles.

(24) In tracing many forms of trouble in a.c. circuits, Ohm's Law for *d.c.* is often used as a matter of simplicity and convenience. The results are not accurate, of course, but with proper allowance for that fact reasonably satisfactory conclusions can be drawn as to the condition of apparatus under test. Thus, with some types of loud speaker "voice" coils, it is customary to measure the d.c. resistance of the coil, and multiply the result by 1½ to obtain a sufficiently satisfactory indication of the a.c. impedance. That process does not, however, work out with all types of voice coils. It fails completely with many other forms of a.c. apparatus. None the less, if the projectionist keeps in memory a good working idea of what inductive and capacitative reactance mean, and how they are related to ordinary, or "straight" or "ohmic" resistance, he can do a fairly good job of trouble-shooting on a.c. apparatus by applying the simple d.c. form of Ohm's Law and plenty of common sense.

Pulsating D.C. and Other Complex Currents

(25) It is important to the projectionist to be able to understand diagrams of the type of Figs. 5A and 5B. Similar drawings are often used to explain the functioning of items of projection room equipment. They constitute a convenient, short-hand explanation of the behavior of a.c. and of complex currents. Assuming Fig.

FIGURE 5A



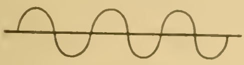


FIGURE 5B

5A to represent a "pure" or "sinusoidal" a.c. of 30 cycles, diagramming current only, begin at the left end of the wavy line. Note that this starts at the central line, or zero current, and rises (current flowing to the left) to a maximum value of 5 amperes, representing peak current in one direction. During the next 60th second the current in that direction declines again to zero, and then begins flowing in the opposite direction; and during the remainder of that 60th second rises to 5 amperes "below the line" or in the opposite direction. The entire sketch is a diagrammatic representation of certain current facts. It might as easily represent voltage, or power. The most important information it conveys, as will be seen, is in the wave shape, or regularity with which the current rises and falls, and therefore the explanatory data of Fig. 5A is often omitted, and the information is given in the simpler form of Fig. 5B.

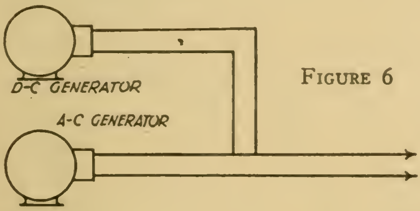


FIGURE 6

(26) Fig. 6 represents two generators, one a.c. and one d.c., both supplying current to a single pair of wires. Generators are not usually connected thus, but the same effect (that of a.c. and d.c. in a single wire) is often produceds in projection room equipment. If it be supposed that, in this case, the d.c. generator is the larger, producing more current than the other, the effective current flowing in the wire can be diagramed as in Fig. 7, A.

The portion of the curve represented by section A of that diagram shows the effect produced with both generators functioning. To the right, section B shows the effect if the d.c. generator were not working; section C shows both generators again functioning; section D, the effect with a.c. generator cut off.

(27) The curves of sections B and D are components, of which the combined curve (sections A and C) is the resultant. A component is one current (or voltage) factor in a complex current or voltage, which latter is the resultant of all the components present.

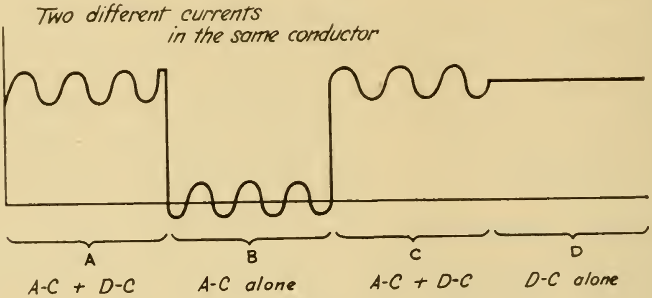


FIGURE 7

(28) The current of sections A and C, Fig. 7, is known as pulsating d.c., rough d.c., fluctuating d.c., etc. It is said to have an a.c. component, or a ripple. All d.c., except that drawn from batteries, is to some extent fluctuating, possessing more or less of an ac. component. A good deal of modern projection apparatus is for filtering out or eliminating the a.c. component in fluctuating d.c.

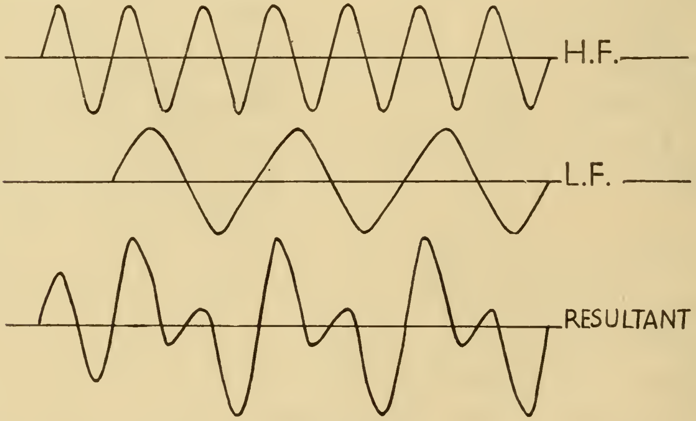


FIGURE 8

(29) If the two generators of Fig. 6 were both a.c. generators producing currents of different frequencies, the effect would be as shown in the bottom curve of Fig. 8. Sometimes the two currents of the upper two curves would be moving in the same direction, reinforcing each other, and producing a surge represented by a peak in the resultant curve. At other times the two currents would be opposing each other, producing a weak or even a zero resultant. Many forms of a.c. used in the projection room are complex resultants which contain within themselves a large number of individual components of many different frequencies. By use of suitable apparatus the components can be separated, just as a.c. and d.c. components of fluctuating d.c. can be separated. The projectionist encounters such separating or filtering apparatus in his ordinary work.

PHASE

(30) When current is first admitted to a d.c. circuit containing a magnetic winding, there is a brief interval during which a field is building up around the winding and, as said, the full current does not flow instantly. It lags slightly behind the application of the voltage. When the applied voltage is removed, as by opening a switch, the current does not disappear instantly; the collapsing magnetic field generates a reinforcing surge of current which sometimes burns the blades of the partially opened switch. In both cases, the action and strength of the current do not synchronize completely with the action and strength of the voltage that created it. This condition is described by saying that the current lags behind the voltage, or the voltage leads the current.

(31) In an a.c. circuit the voltage continuously rises and falls, and if the circuit contains inductance the current may lag behind the voltage. In a circuit containing only inductance, the lag would be equal to ¼ cycle. Current and voltage are said to be "out of phase" with each other.

(32) If d.c. is applied to a circuit containing a con-

denser (see Fig. 9) an immediate rush of charging current follows until the charge in the condenser is built up to a voltage equal to the voltage applied by the generator, after which no further current flows. During the brief interval of time while the charge in the condenser is building up, the current is said to lead the voltage. Current must flow into the condenser before a voltage, or charge, can appear across it. If the generator of Fig. 9 were an a.c. generator, the current would lead the voltage by ¼ cycle, since the circuit contains practically nothing but capacitance.

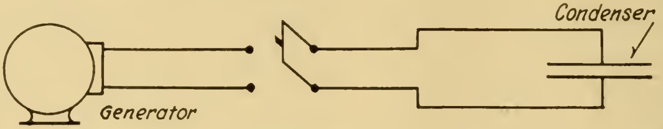


FIGURE 9

(33) In an a.c. circuit containing only pure resistance, current and voltage are in phase with each other. In a circuit containing both, or all three (resistance, inductance and capacitance), voltage and current may be in phase, but are often out of phase to some extent, depending on the values of those three factors.

(34) The power of an a.c. circuit is not equal to E x I, but to E x I x power factor. The power factor is 1, and the power equal to 1 x E x I, when the voltage and current are completely in phase. When voltage and current are not in phase, the power factor is some fraction less than 1, and the power is less than E x I.

PRACTICAL ELECTRICAL CALCULATIONS

Practical Questions

(For answer to each question see statement of corresponding number in Chapter III)

TYPES OF GENERATOR CONNECTIONS, PAGE 41

1. Name three ways of connecting electrical generators.
2. If two 110-volt, 100 ampere generators be wired in parallel, what will be their maximum output voltage? Maximum output current?
3. State the maximum output current and voltage of the above electrical sources if connected in series.
4. State the maximum output current and voltage of four such generators wired in series-parallel.

TYPES OF RESISTOR CONNECTIONS, PAGE 42

5. What factors determine the current through a resistor connected in parallel with other resistors?
6. State the current through a 100-watt lamp connected (in parallel with many other lamps and equipments) to a 110-volt line.
7. What is the filament resistance, at normal operation, of a 20-watt, 110-volt incandescent lamp?
8. What is the formula for resistances connected in parallel?
9. To what degree of accuracy should the projectionist normally carry ordinary electrical calculations?
10. What is the formula for resistances of equal value connected in parallel?
11. If several resistors are wired in series, what is their total effective resistance?
12. If resistors be connected in series with each other and with a source of voltage, does the full voltage of the source appear across each resistor?
13. Explain how voltage drop is made use of in a voltage divider circuit.
14. What is the practical value of a voltage divider circuit?

15. Show how you would find the current and voltage drop through each resistance in a series-parallel circuit, circuit voltage and resistance values being known.
16. Show how you would do the same for wiring arrangements more complex than a series-parallel circuit.
17. Under what conditions is it important for the projectionist to apply simple d.c. calculations covering voltage, current, resistance and power?
18. Is it current or wattage that causes conductors to overheat and burn out? Why are some common electrical units rated for safety in current and others rated in terms of power?

Wiring Calculations, page 48

19. Under what projection room circumstances may the resistance of connecting wires become important enough to justify calculating it?
20. If 8.2 volts at 1 ampere be supplied to a pair of No. 18 wires in the projection room, what voltage can those wires supply to a loud speaker unit located 100 feet distant?
21. If the filament resistance of an incandescent lamp is measured when the filament is cold (using a test instrument that does not pass enough current to heat the filament) will the reading obtained be accurate with reference to the filament resistance under normal (hot) operation? Explain.
22. Does the resistance of an ordinary wire conductor change if it is forced to carry current beyond its normal capacity?
23. Will the resistance of No. 18 wire increase if it be made to carry 8 amperes?
24. How can the correct wire gauge, or size, for any required current, be ascertained?
25. What is meant by the gauge of a wire? How can it be measured? What is a "wire gauge?"

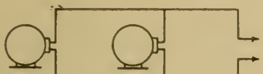
A. C. Peaks, page 52

26. Is the carrying capacity of a wire, in amperes, the same for a.c. as for d.c.?
27. Is the effective or rated amperage of an alternating current the same as the peak amperage reached twice during each cycle? or what fraction of that peak amperage is the rated current?
28. The insulation used for a 110-volt a.c. circuit must withstand what peak voltage twice during each cycle?
29. Is a condenser rated for 110 volts d.c. suited to use across a 110-volt a.c. line?

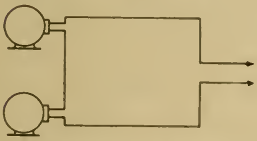
CHAPTER III.

PRACTICAL ELECTRICAL CALCULATIONS

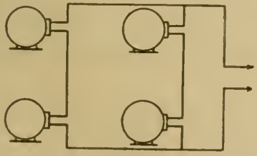
(1) Many circuits used in the projection room are supplied by more than a single source of electrical power. The sources do not usually consist of generators, but of some form of conversion apparatus or circuits, to be discussed later. Regardless of the nature of the power sources they can be connected with each other in several different ways, according to the results required of them. Fig. 10 shows the three most common methods of connecting power sources, when more than one is used. Connections may be parallel (also called shunt or multiple), series, and series-parallel.



Generators in parallel.



Generators in series.



Generators in series-parallel.

FIGURE 10

(2) In the parallel circuit, both generators deliver the same voltage. If they did not, the generator delivering the stronger voltage would force a reverse flow of current through the other generator. Assuming the voltage output of both generators of Fig 10's parallel circuit to be the same, then the voltage difference between the top wire and the bottom wire is just the same as if only one generator were used. The parallel connection only increases current, voltage remaining the same. Amperages supplied by power sources connected in parallel are added to find the total current output.

(3) In series connections the reverse is true. The voltage developed by the top generator must be added to

the voltage developed by the bottom generator to find the total voltage difference between the top wire and the bottom wire. If the generators of the series circuit of Fig. 10 were each capable of delivering 110 volts, the total voltage in the output circuit would be 220. The current would however be only the maximum current that the smaller of the two generators was capable of handling, for the reason that all current in the circuit must pass through both generators to complete its path. A series connection does not increase the total available current, which remains limited by the maximum output of one generator.

(4) The series-parallel circuit of the lower sketch in Fig. 10 may be regarded as equivalent to two 220-volt generators connected in parallel (assuming each single generator to be of 110-volt rating). That circuit delivers 220 volts and the available current output of the two parallel circuits is added to find the total available amperage.

TYPES OF RESISTOR CONNECTIONS

(5) In a d.c. circuit the load into which the generators deliver current is composed of resistances. The simplest connection is the parallel circuit. In such a circuit (shown at the top of Fig. 11) all resistances, whether lamps, motors or other apparatus, are wired directly across the line. All resistances therefore are exposed to the full voltage of the line, and the current through each is governed solely by the line voltage and the ohmage of the single resistor in question. Large and small lamps, motors, etc., can conveniently be connected to the same line in this way, and each will "draw" (that is, permit to pass) exactly that current which the line voltage will force through its resistance.

(6) In the parallel circuit of Fig. 11 suppose R-1 to represent a 100-watt incandescent bulb. Since this is exposed to a voltage of 110, the formula E x I = W gives the current through it: I = W/E or 100 ÷ 110, or approximately .909 amperes. With the current known as well as the voltage, Ohm's Law can be applied to find

the resistance of the filament at normal operation. That resistance, as shown in the diagram, is approximately 121 ohms. A voltage of 110 will drive .909 amperes through 121 ohms, entirely regardless of other connections to this circuit. R-2 can have no effect on the current through R-1, unless the resistance of R-2 is so very low as to amount to a short circuit; in which case a power source of small capacity might not be able to maintain its full voltage and the current through R-1 would drop according to Ohm's Law as the line voltage declined.

(7) R-2 in the diagram may be considered as a 20-watt incandescent lamp. Its filament resistance at normal operation is given as approximately 610 ohms, a value which is accurate enough for practical purposes. The student should find some useful practice as well as amusement in re-calculating that resistance for himself, beginning by calculating the current that will be forced through it by 110 volts.

(8) In a parallel circuit the total current drawn from the source is greater than that flowing through either resistor alone. It is, in fact, the sum of all parallel currents, hence the total effect of placing resistors in parallel must be to reduce the net resistance of the circuit considered as a whole. The formula for the net effect produced by resistors in parallel is: $R = \dfrac{1}{\dfrac{1}{\text{R-1}} + \dfrac{1}{\text{R-2}}\text{, etc.}}$

or, in the case of Fig. 11's parallel circuit,

$R = \dfrac{1}{\dfrac{1}{121} + \dfrac{1}{610}}$. By the ordinary arithmetic of fractions this works out to $R = \dfrac{1}{\dfrac{731}{73810}}$: R =

$\frac{73810}{731}$ = 100 ohms, approximately. This value is of course less than that of the smaller resistor, since a parallel path has been added around that smaller resistor, permitting still more current to flow. The total current flowing is: 0.909 amperes through 122 ohms; 0.180 amperes through 610 ohms; 1.089 amperes altogether.

(9) Students who duplicate these calculations will note that the figures are not carried out to the last possible fraction, but are only approximately accurate. The projectionist will never, in his practical work, have occasion to carry his figuring to absolute arithmetical accuracy, but only to approximate accuracy in which small fractions left over are disregarded.

(10) Where two resistors in parallel are of equal value it is not necessary to use the formula cited above, but only to divide by 2. Thus, if the resistors of the parallel circuit of Fig. 11 were each of 100 ohms value, their net effect in the circuit would be that of one resistor of 50 ohms. If there are three equal resistors divide by 3; if there are four, divide by 4, etc. It is only where parallel resistors are of unequal values that the formula is needed.

(11) In the series circuit of Fig. 11 all current that flows through R-3 must also flow through R-4, and vice versa. Hence, connecting resistances in series has the effect of adding to the amount of resistance an electron must overcome in passing around the circuit. No formula is necessary for resistors in series. Their values add. The total resistance in the series circuit of Fig. 11 is 122 + 244 or 366 ohms. This at 220 volts gives a current of 220 ÷ 366 or about 0.6 ampere. The same current, of course flows through both resistances, which fact involves the very important phenomenon of "voltage drop."

(12) Since the current in the top resistor of the series circuit is 0.6 amperes and the resistance is 122 ohms, the voltage acting across that resistance must, by Ohm's Law, be 122 x 0.6, or 73.2 volts. That is all the voltage that can possibly act across R-3; if there were a greater voltage across that resistance the current flow through it

would be increased. But the total applied voltage is 220, therefore the other 146.8 volts must be across R-4, which checks by Ohm's Law: 146.8 volts drives approximately 0.6 amperes through 244 ohms. In other words, assuming the top wire to be negative, the concentration of electrons at the top of R-3 is equivalent to a force of 220 volts; proceeding toward the bottom wire, the concentration progressively decreases; at the top of R-4 it is equivalent only to a force of 146.8 volts, as compared with the concentration existing at the bottom or positive side of R-4. As commonly expressed, there is a voltage drop of 73.2 volts across R-4, and of 146.8 volts across the higher resistance, R-4, making a total drop of 73.2 + 146.8 or 220 volts for the circuit as a whole.

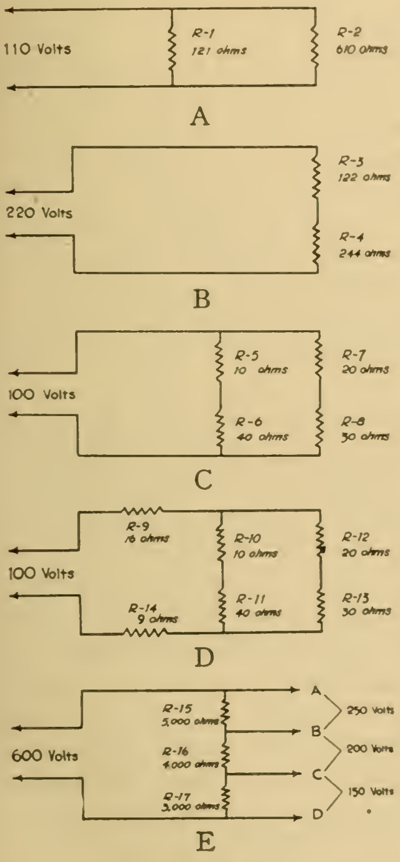


FIGURE 11

(13) Voltage drop is used in practice as indicated in the voltage divider at the bottom of Fig. 11. Note that the total resistance of R-15, R-16 and R-17 adds up to 12,000 ohms, which at 600 volts gives a current, through the divider, of 0.05 ampere. Now 0.05 ampere through the 5,000 ohms of R-15 means a voltage drop across R-15 of 250 volts. (E = I x R.) The same current through the 4,000 ohms of R-16 indicates a drop of 200 volts across R-16. The remaining 150 volts must constitute the drop across R-17,

which checks correctly, since 150 volts divided by 3,000 ohms shows a current of 0.05.

(14) By means of the voltage divider a single source of voltage, in this case 600 volts, becomes several different voltages. The circuit shown yields 600 volts (by connecting to A-D); 450 volts (A-C); 350 volts (B-D) in addition to the potentials shown in the drawing. This arrangement is very common in amplifier power circuits, hence should be thoroughly understood. Note that current through the divider resistors must be considerably higher than the current through any load connected with their output. Thus 15 ohms connected across C-D (150 volts) would seemingly result in a flow of 10 amperes. However, the 10 amperes would have to complete their path through R-15 and R-16 which is impossible; the full 600 volts available could not drive 10 amperes through 9,000 ohms. On the other hand, 150,000 ohms across C-D would add only 150/150,000, or .001 ampere, 1 milliampere, to the 0.05 ampere current of the divider, and would leave the existing distribution of voltage drops substantially unchanged.

(15) In the series-parallel circuit of Fig. 11, R-5 and R-6, in series, total 50 ohms; R-7 and R-8 in series also total 50 ohms. Since the two branches are of equal resistance it is not necessary to use the fraction formula, but simply to divide by 2 to find the total circuit resistance, which is 25 ohms. At 100 volts, this means a circuit current of 4 amperes. Since the two arms are of equal resistance, the total current will divide evenly between them and each arm will carry 2 amperes. If the resistance of the branches were of unequal value, as in the parallel circuit of Fig. 11, the current would divide inversely as the resistance; that is the arm with the higher resistance would have the smaller current, and vice versa. In the series-parallel circuit it is clear that 2 amperes flow through each of the four resistors. The only other information that could possibly be required in connection with this circuit is the individual voltage drop across each separate resistor and since the resistance of each and the current through each is known, the voltage drop in every

case is easily found. The reader should work it out for himself and note that the sum of the voltage drops of each branch totals the full 100 volt drop of the circuit.

(16) In more complex circuits it is a general rule to investigate parallel lines first. The parallel branches of the complex circuit here shown comprise R-10, R-11, R-12 and R-13, and for convenience have been given the same values as in the series-parallel circuit just above it. The effective resistance of the branches of this complex circuit is therefore 25 ohms, as before, but the current through them is not 4 amperes because the voltage across them is something less than 100 volts; less by the difference resulting from the voltage drops across R-9 and R-14. However, since the effective resistance of the parallel branches is 25 ohms, and since that resistance is in series with R-9 and R-14, the total circuit resistance can easily be found; it is 25 + 16 + 9 or 50 ohms; the effective circuit current is therefore 2 amperes. That current through 16 ohms (R-9) represents a voltage drop of 32 volts; through the 25 ohms of the parallel arms a drop of 50 volts and through R-14 a drop of 18 volts, making 100 volts in all. Nothing further remains except to investigate the voltage drops in the parallel arms. The circuit current is 2 amperes, therefore, in this case, 1 ampere flows in each parallel branch. The drop through R-10 is therefore 10 volts, and through R-11, 40 volts, making 50 volts in all across the parallel branches; the right-hand branch is similarly easy to figure out. Do it.

(17) Simple d.c. calculations of the type just reviewed are of great practical importance to the projectionist in installing new apparatus, making wiring changes and tracing trouble. If the student is not perfectly clear as to what he has just read he should go back over it, as many times as may be necessary, to make him completely confident of his ability to handle simple calculations of this kind, which involve no mathematics beyond the simple, schoolboy arithmetic of fractions.

(18) The simple formulas just reviewed also help explain a common fact that often puzzles beginners. Flow of excessive current through any conductor tends

to cause the conductor to heat, and if heated sufficiently it may "burn out"—that is, melt. Conductors of all types are rated accordingly, with a safety factor cited either in terms of amperes or of watts. A wire may be said to have a safe carrying capacity of so many amperes. On the other hand, a resistance unit is likely to be rated at so many watts. The beginner sometimes asks whether it is power (wattage) or only current (amperage) that is responsible for damage to overheated conductors. Actually, it is wattage. But since in the case of any specific conductor the resistance is known (so many ohms per resistor unit or per foot of wire) and since wattage is I^2R, the manufacturer can easily figure the danger point in either amperage or wattage. The user of the conductor (a projectionist, for example) is likely to find amperage easier to measure than wattage (ammeters are more common and less costly than wattmeters; also more easily used). Wire and fuse capacities are almost always rated in terms of amperage. Resistance units, on the other hand, are usually rated in terms of wattage. This is actually a matter of indifference to the projectionist, so long as he takes care to keep within the safe limits prescribed.

Wiring Calculations

(19) The projectionist is often called on to install or connect new items of apparatus, or to repair or revise power connections of existing items. The wiring involved in such work may extend over considerable distances, say from the projection room to the meter board, or from the projection rooms to the loudspeakers backstage; or in other cases the wiring may be called upon to carry heavy currents, on the order of 50 amperes or more. In such cases the resistance of the connecting wires may become important. In the sample calculations just given, resistance units only were considered and it was tacitly assumed that the connecting wires were so short that their resistance was negligible. This is not true of long runs of wire or of heavy current. The projectionist must

know how to allow for wire resistance whenever his duties require him to deal with projection room power wiring.

(20) As an example consider a loud speaker winding which may receive its excitation current from a projection room 100 feet distant. The total length of the two feed wires may therefore be 200 feet. That length of No. 18 wire has a resistance of approximately 1.2 ohms. If the speaker requires 1 ampere of operating current the voltage drop in the connecting line will be 1.2 volts. For a 7-volt speaker unit this means a total of 8.2 volts is required from the supply unit. If the source does not have that capacity, larger wires must be used in order that resistance and therefore voltage drop be reduced. Two hundred feet of No. 14 wire have a resistance of only about 0.5 ohm, hence will serve the speaker satisfactorily when connected with a power source capable of delivering only 7½ volts.

(21) In addition it must be remembered that current passing through a conductor raises its temperature; also that the resistance of a metal conductor increases when the conductor becomes heated. An excellent example is provided by any 110-volt incandescent lamp. The filament resistance, as measured with an ohmmeter, is meaningless in practice. For the ohmmeter is an instrument using insufficient current to heat the filament appreciably, hence the reading obtained gives the cold resistance only. In normal operation that resistance will be considerably higher if the filament be tungsten or other metal, and considerably lower in the case of a carbon filament. The resistance of the filament under operating conditions is not determined with an ohmmeter, but with a voltmeter and ammeter and calculation according to Ohm's Law.

(22) In a similar way, though to less extent, the cold resistance of a conductor, as rated by its manufacturer, may differ from its resistance in use if it is carrying enough current to heat it appreciably. When new projection room wiring is to be installed, allowance for the possibility of temperature rise in use should be made in advance.

(23) As a practical example, suppose a new line is to be run to 8 loud speaker units of the type requiring 1 ampere at 7 volts field excitation, located 100 feet distant and connected in parallel. Use of No. 18 solid wire, with a cold resistance of 1.2 ohms per 200 feet, will produce a voltage drop in that wire (when cold) of 8 amperes x 1.2 ohms, or 9.6 volts. Under those circumstances it may be hastily assumed that a source located in the projection room, which is capable of delivering 8 amperes at 16.6 volts will fully supply the needs of the speakers. It will not! The current, 8 amperes, will overload a No. 18 wire enough to raise its temperature appreciably; therefore its resistance will rise above the assumed value of 1.2 ohms and the voltage drop will rise above 9.6 volts. This will occur even with a current of somewhat less than 8 amperes. The speakers will not receive correct excitation. Additionally, the temperature increase will have a very unfavorable effect on the life of the wires and their insulation, as well as, possibly, on nearby apparatus. Still further, such overheating represents a perpetual waste of electricity, the power being converted into heat which serves no useful purpose, yet must be paid for.

TABLE NO. 1

No. Gauge	Diameter of Solid Wires in Mils	Area in Circular Mils	Rubber Insulation, Amperes	Varnished Cambric Insulation, Amperes
18	40.3	1,624	3	
16	50.8	2,583	6	
14	64.1	4,107	15	18
12	80.8	6,530	20	25
10	101.9	10,380	25	30
8	128.5	16,510	35	40
6	162.0	26,250	50	60
5	181.9	33,100	55	65
4	204.3	41,740	70	85
3	229.4	52,630	80	95
2	257.6	66,370	90	110
1	289.3	83,690	100	120
0	325.0	105,500	125	150
00	364.8	133,100	150	180
000	409.6	167,800	175	210
		200,000	200	240
0000	460.0	211,600	225	270

(24) Table No. 1 may be used to find the correct wire gauge, or number, for any required current. Look up the current to be carried in the right-hand column or first

column from the right (according to the type of wire insulation). The correct wire gauge (for solid wire) will then be found in the extreme left-hand column. Table No. 2 gives similar information for stranded wire.

TABLE NO. 2
STANDARDIZED STRANDING

Strands		Cable		Allowable Carrying Capacities in Amperes		
No. of Strands Mils Dia.	B. & S. Gauge No.	Area in Cir. Mils	Outside Dia. over Copper	Table A Rubber Insulation	Table B Varnished Cloth Insulation	Table C Other Insulation
7/ 25	22	4,490	.075	15	18	20
7/ 32	20	7,150	.096	20	25	25
7/ 40	18	11,370	.120	25	30	35
7/ 51	16	18,080	.153	35	40	50
7/ 64	14	28,740	.192	50	60	70
7/ 81	12	45,710	.253	70	85	90
7/ 91	11	58,000	.273	80	95	110
7/102	10	72,680	.306	90	110	130
19/ 64	14	78,030	.320	100	120	150
19/ 72	13	98,380	.360	125	150	175
19/ 81	12	124,900	.405	150	180	210
19/ 91	11	157,300	.455	175	210	250
19/107	*	217,500	.540	225	270	325
19/114	9	248,700	.570	250	300	350
37/ 91	11	306,400	.637	275	330	400
37/ 97	*	347,500	.679	300	360	450
37/102	10	381,200	.714	325	390	500
37/116	*	484,300	.798	400	480	600
61/102	10	633,300	.918	475	565	700
61/107	*	698,000	.963	500	600	750
61/114	9	788,500	1.030	550	660	825
61/121	*	893,100	1.090	600	720	900
61/128	8	1,007,000	1.150	650	780	1000
91/114	9	1,191,000	1.250	725	870	1125
91/128	8	1,502,000	1.410	850	1020	1350
127/114	9	1,660,000	1.480	900	1100	1460
127/128	8	2,097,000	1.660	1100	1300	1700

*These individual strands are odd sizes not listed in the American or B. & S. Wire Tables.

(25) The wire "gauge" refers only to the diameter of the wire. To rate wire according to its diameter in mils (thousandths of an inch) would be clumsy: it is easier to talk of No. 8 wire than of wire 128.5 mils diameter. Each size wire in common use is assigned a standard gauge number, as the table shows. The gauge of any wire or strand may be found by stripping away the insulation, measuring the diameter of the metal with a micrometer, and referring to the tables. Or with even less effort, by use of a "wire gauge," illustrated in Fig. 12. The slots, not the round openings, are used for measuring.

The wire (stripped of insulation) must fit the slot snugly, but without trace of binding. The gauge of the wire is shown by figures stamped opposite each slot.

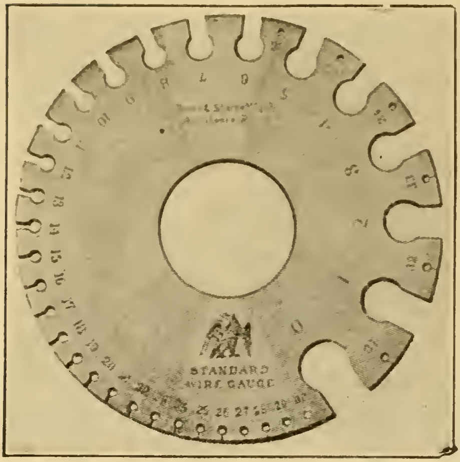


FIGURE 12

A.C. "PEAKS"

(26) The current carrying capacity of any wire is approximately the same whether the current be a.c. or d.c., but that is not always true of fuses, nor is it always true of the voltage rating of insulation.

(27) Figs. 5A and 5B show graphically that alternating current varies continuously in amperage, reaching a peak of maximum current in one direction and immediately dropping off toward zero; reversing its direction of flow and again reaching a peak of maximum current, and so on. A wire carrying a.c. is heated by the current passing through it in proportion to the current strength; that is, heated strongly when the current reaches maximum value and not heated at all during those portions of each cycle when the current is zero. The effective heating power (or working power) of common a.c. as supplied in power lines and diagrammed in Fig. 5, is the same as that of a smooth d.c. having .707 the amperage of the a.c. *peaks.* Alternating amperages are rated accordingly. The rated amperage of a.c. is never the peak amperage, but .707 the peak amperage. Since the heating effect is also .707 the peak amperage, a wire suited to carying 14 amperes d.c. is equally well adapted to carrying 14 amperes a.c., in spite of the fact that the alternating current reaches nearly 20 amperes, momentarily, at the peak of each alternation.

(28) The curves of Fig. 5 refer essentially to voltage as well as to current. The voltage as well as the current

in an a.c. line rises and falls between maximum and zero twice during each cycle. Insulating materials, which are used to confine the current to the path intended for it and prevent it from leaking back to positive through some other, accidental path, are sometimes punctured, or chemically destroyed, by a flash-over of current occurring at moments of maximum voltage. Since such a flash-over or spark through the insulation requires only an instant of time, insulation used with a.c. must be capable of withstanding the voltage peaks, not the mere rated voltage which is only .707 the peak value. In a common 110-volt a.c. supply line the peak voltage rises to 155.5 volts twice during each cycle, an increase over the rated value of 41%. Voltages of irregular or "non-sinusoidal" a.c. may have momentary peaks much more than 41% above their rated or effective value. The insulation used must be capable of withstanding the peak surges.

(29) Parts in which insulation is of special importance, condensers for example, must be replaced with due caution. A condenser rated only for 450 volts *d.c.* is not likely to last long if exposed to a 450-volt alternating current.

ELECTRICAL APPARATUS COMPONENTS

Practical Questions

(For answer to each question see statement of corresponding number in Chapter IV)

1. Must projection room electrical equipment conform to safety requirements?
2. Are the requirements stringent and enforced by law?
3. What is meant by "approved" electrical apparatus?

WIRING, PAGE 59

4. What precaution taken in advance will minimize the chance of conductors being overloaded?
5. Does overloading a conductor cause it to deteriorate?
6. When would you use solid copper wire? Stranded wire?

SPLICING AND SOLDERING, PAGE 60

7. What precautions are needed in preparing a wire for mechanical connection to a binding post?
8. What is a "lug"?
9. How is insulation removed from heavy wires?
10. How are wires spliced?
11. Does a splice form a perfect electrical contact?
12. Why is a poorly soldered electrical connection wrong and dangerous in the projection room?
13. What is meant by welding?
14. Explain what happens when a soldered connection is made.
15. What are the requirements of good soldering?
16. Why must the metals to be soldered be thoroughly clean?
17. Why is flux used?
18. What is flux?
19. What flux should be used for sound equipment connections?
20. What sources of heat should be available for soldering?
21. What is tinning?
22. How should heat be applied in soldering?
23. What precaution is necessary while the connection cools?
24. How are solder connections tested?
25. How is a wire soldered to a hollow lug?

INSULATION, PAGE 66

26. How are electrical wires insulated?
27. How is insulation restored after wires have been spliced?
28. Is insulation damaged by overloading conductors?

CONDUIT, PAGE 67

29. Why is conduit used in the projection room?
30. What is the commonest form of conduit used in the projection room?
31. Describe some common forms of conduit fittings.
32. What is flexible conduit? BX? Greenfield?
33. What is metal strip?
34. What factors govern the type and size of conduit used?

FUSES, PAGE 69

35. What is a fuse?
36. What is a cartridge fuse?
37. What is a plug fuse?
38. What are midget fuses? Grasshopper fuses?
39. Why is an ample supply of spare fuses necessary?
40. What determines the proper size fuse to use in any fuse socket?
41. Why is "boosting" fuses poor practice and dangerous?
42. How should fuse sockets and fuseboards be marked?

SWITCHES, PAGE 72

43. Describe a single-pole, single-throw knife switch.
44. Describe a double-pole, single-throw knife switch.
45. Describe a double-pole, double-throw knife switch.
46. How should switches be fused?
47. How should knife switches be mounted?
48. Describe an enclosed, spring-operated knife switch.
49. What is a rotary switch?
50. What is a toggle switch?
51. Describe a power switchboard.
52. How are power switchboards mounted?

RESISTORS, PAGE 77

53. What is a resistor?
54. Describe some common types of resistors.
55. How are resistors rated?

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56. Explain the resistor color-code.
57. What is an adjustable resistor? A tapped resistor?
58. What is a rheostat?
59. Describe some common types of rheostats.
60. What is a potentiometer?
61. What is a resistance pad?
62. How are rheostats and potentiometers rated?
63. Are all rheostat and potentiometer resistance elements wire-wound?
64. Can a wire-wound rheostat always be substituted for a composition type rheostat of the same rating and taper? Why not?

INDUCTIVE WINDINGS, PAGE 82

65. How are inductors rated?
66. Describe some common types of inductance coils.
67. Are iron-core inductors used at all frequencies?

TRANSFORMERS, PAGE 84

68. What is a transformer?
69. What types of current, applied to one coil of a transformer, will generate a voltage in the other coil?
70. Does change in the strength of a magnetic field generate voltage in any conductor lying within that field?
71. What is a primary coil? Secondary coil?
72. What is a step-down transformer Step-up transformer? 1:1 transformer?
73. Which coil of a transformer is the primary and which the secondary?
74. Can a transformer have more than one secondary coil?
75. What is an autotransformer?
76. How are transformers rated?
77. What type cores are used in high frequency transformers and inductors?
78. Why are cores laminated?

ELECTRICAL CONDENSERS, PAGE 87

79. Name two types of electrical condensers in common use.
80. Describe the construction of a paper condenser.
81. Describe the construction of an electrolytic condenser.
82. Can ordinary electrolytic condensers be used in a.c. circuits?
83. How are condensers rated?

84. What precautions should be taken in selecting condenser replacements?
85. What is the formula for condensers connected in parallel? In series?

Tubes, page 89

86. Can electric current flow through liquids, gases and vacuum?
87. Explain conductivity in liquids.
88. Explain conductivity in gases.
89. What is emission and how can it be promoted?
90. How can a cathode sealed in glass be heated?
91. What is meant by plate impedance in a vacuum tube?
92. What factors influence plate impedance?
93. How is cathode space charge neutralized in a gas-filled tube?
94. What is meant by rectifying a.c.?
95. By what means can a three-element vacuum tube amplify the pattern of an alternating or fluctuating direct current? Explain.
96. What is a triode?
97. What is a tetrode?
98. What is a pentode?
99. What is a beam power tube?
100. Describe the structural details of some common tube types.
101. How does a metal tube differ from a glass tube?
102. Explain the action of a photoelectric cell.

CHAPTER IV

ELECTRICAL APPARATUS COMPONENTS

(1) The electrical equipment of the projection room consists of wire, insulation, switches, fuses, resistance units, condensers, magnetic windings of several kinds, tubes, and other parts or components, certain combinations of which are grouped together to form a single apparatus unit, such as an amplifier for example. The various apparatus units are interconnected with each other and with the source of power. Every connecting wire, all insulation, and all component parts must conform to definite safety specifications because of the risk of projection room fires.

(2) At all times while a show is in progress the projection room contains several thousand feet of film which will ignite very readily, burn furiously, emit enormous volumes of black, poisonous smoke, and make an extremely hot fire which is very hard to put out. If the projectionist is not badly, perhaps fatally, burned in such a blaze he may be gassed into unconsciousness and left for the fire to bring fatality. A few such cases occur every year. Danger to the lives of the audience is present in any projection room fire, even a small one, because of the possibility of panic. The safety requirements designed to prevent a fire from starting through electrical faults are very stringent; they are insisted upon by insurance companies and in most locations are enforced by law.

(3) All electrical wire, apparatus and components used in the projection room should bear the legend: "Approved by Underwriters," meaning that a sample has been inspected and passed upon by the laboratory of the National Board of Fire Underwriters. Approved materials may be accepted without question as suited to the use for which approval was given. All other material should be

approved by the local authorities before it is used. All apparatus and components must be installed in accordance with the safety requirements of the National Electric and local codes. In some instances the code may not apply, in which case the projectionist must use his own common sense, remembering always that the presence of cellulose nitrate film requires generous margins of safety in all electrical work.

WIRING

(4) External wiring—meaning that which connects apparatus units with each other or with the source of power—should never be overloaded. Reference may be made to Tables 1 and 2, pages 50 and 51, when in doubt. Overloading, however, does not usually occur when a pair of wires are first put in. It develops afterward through the careless practice of adding new loads to existing wiring in preference to installing new wires. The tendency to plug into an existing outlet, or connect to an existing switch, rather than go to the expense and trouble of running a new line back to the switchboard or meter board, is natural; but it is dangerous unless examination of the wire and reference to the table shows that the additional current will not overload the conductor. If the wires were oversize to begin with (if the projectionist will make it a consistent habit to specify oversize wires every time a new line is run) the chance of overload resulting from subsequent apparatus changes is greatly reduced, and the expense of running in new lines for every small change avoided without compromise with safety.

(5) Copper wire does not deteriorate greatly if not subjected to overload. However, if consistently overloaded it does. The prolonged heat, resulting from flow of excessive current through the conductor, makes the copper brittle. An overloaded wire will tend to break under mechanical strains which it could easily withstand if it had not been made brittle through misuse.

(6) Commercial copper wires are of two types, solid and stranded. The stranded wire is preferred where flexibility is needed, being less likely to break when re-

peatedly bent or twisted. Connections are more easily made with the solid type, which is preferred wherever the wire is permanently and immovably installed.

SPLICING AND SOLDERING

(7) When two wires are joined, or when a wire is to be fastened to an apparatus unit or component, it is very essential to secure a good and permanent metal-to-metal contact. Connections to switches and other components are usually made mechanically. The connection post of the component part ordinarily consists of a metal bolt and washer. The bolt is unscrewed; insulation is removed from the end of the wire to be attached, the wire thoroughly cleaned and bent to fish-hook shape. This hook is looped around the shaft of the bolt, under the washer, and the bolt screwed down again until the wire is held in firm contact. The chief requirement is to make sure that all insulation has been thoroughly and cleanly removed from the wire; at the same time to be sure that the wire has not been nicked or otherwise damaged in the course of scraping the insulation away. Special precautions are needed with stranded wire of the smaller sizes. One or two strands may be cut through in the course of removing the insulation; or one or more strands may not be caught permanently under the washer. A loose strand may bridge across to a neighboring wire or connection post, creating a short circuit. It is very necessary to watch out for these things when working with stranded wire.

(8) A superior connection to a binding post of the type referred to is made by use of a "lug." This is a small piece of metal, having a hole drilled in it through which the clamping bolt is passed, the wire being soldered to the metal of the lug. Lugs are shown at E and F, Fig. 13. The flat extensions to the right are pierced by the bolt holes. The wire is soldered into the cup-like receptables at the left of the lugs. For small wires the cup-like receptacle may be replaced by a flat metal extension, on which the wire is laid, and soldered.

(9) A and B of Fig. 13 show two ways of removing insulation from heavy wires. In most cases, either will

serve. The important point is to get all the insulation off, so the wire is entirely clean and shiny. When using method B, however, care must be exercised not to let the

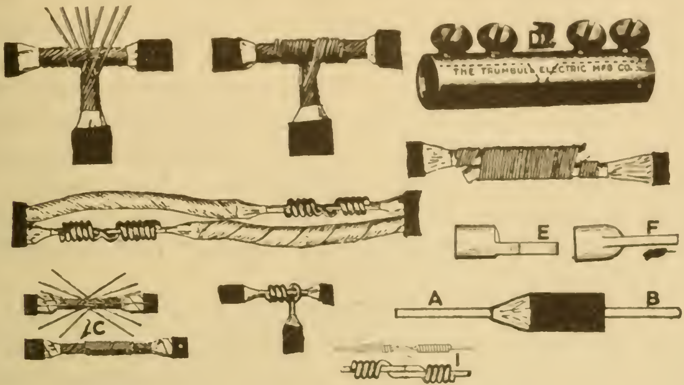

FIGURE 13

knife contact the wire heavily, since a knife cut, especially with small wires, will cause the wire to break very easily.

(10) The remainder of Fig. 13 shows several methods of splicing two or more wires together. The splice most largely in use today is shown at I. Where a pair of wires are to be spliced it is done as shown at middle left—the splices are not placed opposite each other, but each is opposite an insulated portion of the other wire of the pair.

(11) Mere splicing seldom makes a perfect and permanent electrical contact, and is never to be trusted over a period of time unless solder is added. However tightly twisted, a splice may loosen or pull apart under mechanical strain. Also, the surface of the wires of an unsoldered splice is subject to corrosion, which impairs the conductivity of the contact. Many apparatus components are not equipped with bolt-and-washer binding posts to which wires may be connected mechanically, but only with lugs, usually flat, though sometimes hollow ones, and wires must be soldered in place.

(12) The projectionist will sometimes have occasion to make soldered connections, and he may have to make them quickly in time of trouble, hence it is essential that

he understand the process of soldering very thoroughly. A poorly soldered connection in a power line may be a fire hazard, or at the least the cause of serious trouble. In sound apparatus it may produce noisy sound, or temporary, "mysterious" stoppages of sound. Since there are hundreds of soldered connections in any sound equipment, and since almost all of them may and probably will cause trouble if improperly made, and since the exact source of such difficulties is not easy to find, it is necessary that every connection be a good one. As a matter of routine precaution all the soldered contacts in a sound system should be inspected once a year, and those that look doubtful in any way remade.

(13) Soldering is a special form of welding. If two copper conductors be brought together and extreme heat applied, the surfaces of the metals will melt into each other, and when the heat is removed the two metals will have become one. This is "welding." Welding is not used in the projection room because of the extreme heat required for it. Soldering is a modification of the process which works at a far lower temperature.

(14) If two lumps of sugar are brought together and a thin film of water is run between them (at temperatures below the freezing point) the water will melt into the surface of each lump and when it freezes it will freeze the sugars into one piece. This is essentially the process of soldering. Solder is an alloy of metals having a low melting point, and capable when molten of dissolving into the surfaces of other metals just as liquid water dissolves into a lump of sugar. When the source of heat is removed the solder freezes (solidifies) and holds the two metals together mechanically; moreover, because it has dissolved into the two surfaces, it provides a most intimate metal-to-metal contact of excellent conductivity. But this result will be obtained only if the soldering is properly done. There are a number of reasons why the process sometimes fails. It must be applied properly by projectionists, with certain precautions.

(15) Soldering involves three requirements: cleanliness, the right "flux," and the right heat.

(16) If two cubes of sugar were coated with a layer of grease or other dirt and water were run between them and frozen as previously described, the sugars would not be joined. The intervening layers of oil, or of dirt impervious to water, would prevent the water from soaking into the sugar, hence there would be no bond. Similarly surfaces to be soldered must be thoroughly clean; bright and shining. If they are not, the solder cannot merge with them, won't hold.

(17) Most common metals, including copper, develop a film of corrosion on exposure to air. When that film is at all thick it gives the metal a dull appearance. Scraping it away reveals shining metal beneath. But no mechanical scraping clears away the corrosion satisfactorily for purposes of soldering because a new, as yet invisibly thin layer, forms instantly. Freshly cleaned copper, bright and shining, may be compared to a cube of sugar which has been coated with an invisibly thin layer of oil. It will not hold solder. The last layer of invisible corrosion must be removed chemically at the time solder is applied. This is the function of the flux.

(18) The flux may be a paste or liquid sold in a small tin can or it may be a paste or liquid or powder carried inside a hollow wire of solder metal. It is either an acid or a substance which exhibits acid properties at the temperature of soldering. As such it acts chemically on the layer of corrosion and dissipates that layer, permitting the molten solder to dissolve into the metal.

(19) Some fluxes are much more strongly acid than others. The strong acids make the work easier; where they are used the surfaces need less thorough scraping; but they are likely to corrode the joint afterward. Strong fluxes should never be used in connection with sound apparatus, where the voltages are often only fractions of one volt and the currents may be a thousandth of an ampere or less. Slight corrosion can interfere disastrously with such weak voltages and currents, interrupting the sound, or making it noisy, or causing the equipment to pick up and reproduce hum. The only safe flux to use with sound equipment is rosin flux. Rosin has no

acid properties when it is cold; therefore will not cause corrosion.

(20) The heat needed for soldering may be supplied by a soldering "iron"—actually, the iron is copper-tipped —which is internally heated by an electrical heating coil; or a torch may be used. Both soldering irons and torches come in several sizes. A thin, electrically heated iron is needed for work on complex apparatus. A larger iron, giving more heat, is necessary for heavy work. There are small alcohol blow-torches that give a very thin-pointed, hot flame, and larger gasoline-fueled torches for bigger jobs. The wrong source of heat will do a poor job. The projection room should be properly equipped accordingly.

(21) The first process in soldering is "tinning." This means coating the surfaces to be joined with a thin film or layer of solder, which makes the rest of the work much easier. The tinned surfaces are then brought together, and soldered into one. Some surfaces, such as soldering lugs, are supplied pre-tinned in the factory; and some types of wire used in modern apparatus are in effect pre-tinned wires. Tinned surfaces need only moderate cleaning.

(22) The heat must be properly applied. NEVER melt solder and flux and apply them to cold metal. The metal will chill them. The result will be a "cold joint," having no permanence and only temporary conductivity through some pin-point areas where the heat was locally adequate. These pin-point connections will break down when internally heated by the current passing through them. A cold joint, even if good initially, does not stay good. The proper procedure is to heat the metals to be joined, and let *them* melt the solder and the flux. This makes a cold joint impossible. Sometimes metal studs, binding posts or lugs will refuse to heat up sufficiently to melt solder because they are in contact with large masses of metal which conduct the heat away as fast as it is applied. Prolonged heating may damage internal apparatus associated with such studs or lugs, and is dangerous accordingly. If possible, remove the lug, solder

the wire to it first and then restore it. If this is not possible, use a fiercer source of heat, as by substituting the alcohol torch for the soldering iron, so as to apply heat faster than it can be conducted away.

(23) Proper cooling is as important as proper heating. Until the solder has "set" the connection must not be disturbed mechanically. For that reason some men prefer to splice wires firmly, or twist them firmly about lugs or posts, so they will remain rigidly in place while the solder is cooling. But no one with a steady hand needs such extreme precautions, and they are undesirable from the point of view of testing the connection.

(24) When the joint is entirely cool it may easily be tested if there is no physical connection, such as a splice. If the solder constitutes the only mechanical bond, the test is simply to try to tear the two surfaces apart. A well-soldered connection should resist any strain that the wire is capable of withstanding. It should be possible to lift a heavy piece of apparatus by one soldered connection, without injury to the connection; if it does not hold, it was not a good joint. Since splicing, or wrapping the wire around a lug, provide mechanical linkage which makes such tests meaningless, such joints cannot be effectively tested and the permanence of their conductivity remains a matter of doubt. For corrosion may set in, if the joint is not perfect, either through exposure to air or through the action of an acid flux; rosin flux may produce a "rosin joint" of very low conductivity, the cooled rosin forming a kind of glue which holds the wires together physically but constitutes a layer of insulation between them. Tugging at a wire which is not mechanically held in place breaks all such connections at once.

(25) A hollow lug, like E and F in Fig. 13, is tinned inside, then is heated until its cup holds a pool of molten solder. A previously tinned wire, stripped of its insulation as at B, Fig. 13, is then inserted into the pool, and the heat removed. When the solder has chilled, a strong man will not be able to pull the wire free. We have dealt thus extensively with solder joints because much trouble, noisy sound, etc., is traceable to imperfect contacts.

INSULATION

(26) The term insulation refers to any substance which is a very poor conductor and is used for the purpose of confining electrical currents to the paths intended for them. Several kinds of insulation are used on wires. Cotton soaked in wax, tar, rubber, or combinations of those substances are most common. Asbestos is used for wires exposed to high temperatures, as in the supply line to the projection arc. Wires bunched together in a cable may be insulated with wrappings of dry paper. Insulation is stripped away from wires for purposes of soldering or splicing with special tools made for that purpose, or simply with a knife. If the insulation is of a sticky or tarry nature, the last traces of it must be scraped from the wire with the back of the knife blade. If the insulation is oiled cotton, the edge of the blade may be used to scrape the wire very slightly, so as to remove the last traces of oil.

(27) When a splice has been made, suitable insulation must be restored. This is done by wrapping the splice with insulating tape. Such tapes are of two types—tarred cotton and rubber. Both will remain in place when firmly wrapped around the splice, but the rubber tape will not always stay in place. Whenever it is used a wrapping of tarred cotton (so-called "friction" tape or electricians' tape) is put on over it. Where the insulation must give protection against voltages of the order of 1,000 volts or more, a tape made of empire cloth may be used. This cloth is cotton, or sometimes linen, specially impregnated with materials of extremely high resistance. Rubber tape and friction tape are put on over the empire cloth.

(28) Most insulation is damaged by heat. Friction tape dries out and loses its hold. Rubber, whether part of the original insulation of the wire or added subsequently as a tape, becomes brittle, cracks, and loses its resistivity. Insulating material used for mounting apparatus and component parts thereof is damaged in various ways, depending upon its nature. Ceramic insulation and bakelite are most nearly immune to the attacks

of heat. Many of the moulded compounds used for insulating apparatus and components melt or crack. Overloading wires and apparatus is dangerous to insulation as well as to conductors, and must always be avoided.

5. CONDUIT

(29) With very few exceptions, all electrical wiring between units of projection room apparatus, or between such units and the power source, is protected by some form of conduit. This is required by safety regulations. The object of the conduit is to protect the wires against mechanical injury which may tear either them or their insulation, with possibility of a resulting flash-over of current that may start a fire.

(30) The commonest form of conduit is metal pipe, ranging in diameter from ½ inch up to almost any size required. The diameter used is governed by the diameter and number of wires to be carried in the conduit. It is always desirable to install oversize conduit, so that additional wires can be pulled in for future needs. In installation, corners may be negotiated either by bending the pipe or by use of suitable fittings. Fittings are also used at points where it is desired to have the wires enter or leave the conduit. It is advisable to install a surplus of fittings of the latter type for convenience in making future changes or connections.

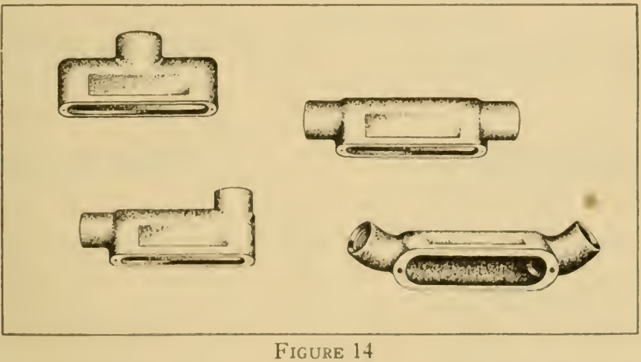

FIGURE 14

(31) Some fittings are shown in Figs. 14, 15 and 16. An almost infinite variety of fittings is available, suited to almost every possible requirement. The side openings are covered with thin metal plates which can be removed and which may or may not be pierced with insulated openings through which wires can be led into the conduit or out of it.

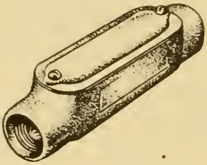
FIGURE 15

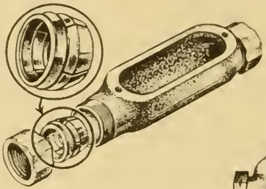
FIGURE 16

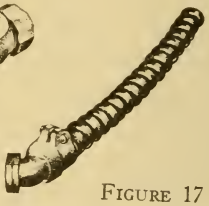
FIGURE 17

Fittings are attached to the conduit either by means of screw threads, or by special connectors which grip the smooth outer surface of the conduit and save the labor of cutting a thread on it.

(32) Flexible conduit is easier to handle than pipe. It also is necessary wherever a moderate degree of flexibility is required. Flexible conduit is often supplied with insulated wires already installed in it, ready for connection. In that form it is known as BX. The conduit alone is sometimes called "Greenfield." Flexible conduit, terminating in a 45° fitting for connection to an apparatus unit, is shown in Fig. 17.

(33) Metal strip, less common than either pipe or flexible conduit, consists essentially of a thin metal trough affixed to the wall with nails or screws. The wires are placed in the trough, and a flat metal cover snapped on or otherwise affixed, enclosing the wires in metal. Suitable fittings are available. In general strip is not as strong as conduit, but is easy to handle and makes a very neat appearance.

(34) The type and size of conduit, the number of wires carried in it, the way it is mounted to the walls, the

use of fittings, and other details are subject to safety requirements which vary locally, and which must be consulted whenever projection room wiring is to be installed or altered.

FUSES

(35) A fuse is a short, special conductor constructed of metal alloy which will melt at a relatively low temperature. It usually is mounted in a plug or cartridge to enable quick and easy replacement. Fuses are rated in amperes. A 15-ampere fuse, for example, will conduct 15 amperes without sustaining damage, but will melt at less than 20 amperes. When the fuse melts ("burns out") it opens the circuit of which it is a part, thus protecting the wire and apparatus against overload. It performs the function of an automatic switch which opens itself when the current through it becomes excessive. Unlike a switch, it cannot be closed again, but must be replaced. The use of fuses is required by all safety codes, which further require that, for use in theatres, the fuse conductor be completely enclosed. In some few cities, however, local codes demand fuses of the open variety which consist only of a length of fusible wire, in circuits supplying current to projector light sources. (See Fig. 18.) This is to prevent "boosting" the fuse, which may be done in a number of ways if plug or cartridge fuses are used, while if an open fuse be boosted, the fact is clearly visible at a glance.

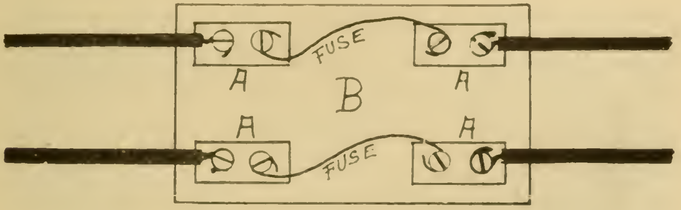

FIGURE 18

(36) Enclosed cartridge fuses are illustrated in Fig. 19. The type there shown is equipped with a special mechanism to blacken its outer surface when the fuse wire melts, thus indicating which one of a row of fuses has given way. Where there is no such provision the fuses may be touched; the one that has "blown" will feel warm for some time afterward. Some cartridge fuses contain replaceable elements. The brass ends can be unscrewed, and a new strip of fuse metal inserted. The cartridge fuse fits into clips as illustrated in Fig. 20.

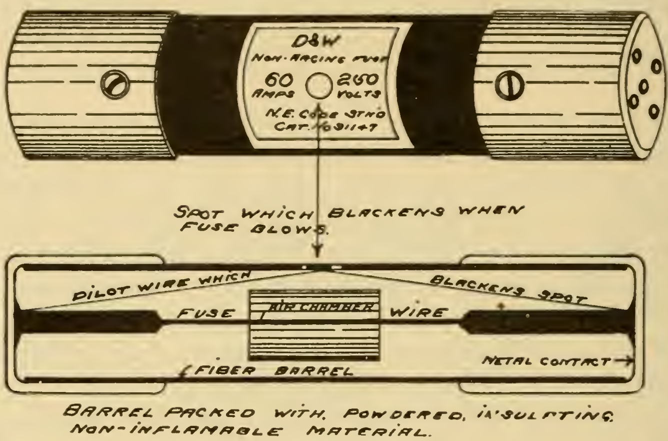
D&W
NON-ARCING FUSE
60 AMPS
250 VOLTS
N.E. CODE STND
CAT. No 91147
SPOT WHICH BLACKENS WHEN FUSE BLOWS.
PILOT WIRE WHICH BLACKENS SPOT
FUSE WIRE
AIR CHAMBER
FIBER BARREL
METAL CONTACT
BARREL PACKED WITH POWDERED INSULATING NON-INFLAMABLE MATERIAL.

FIGURE 19

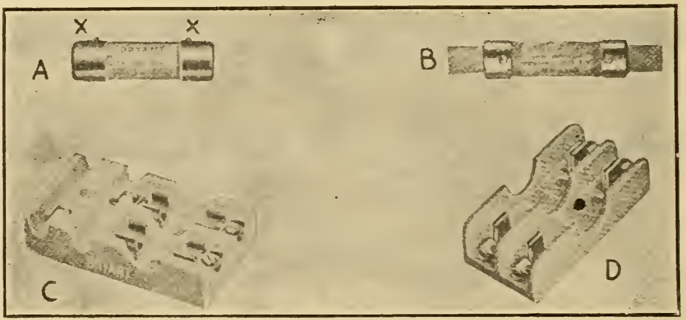

FIGURE 20

(37) Plug fuses are illustrated in Fig. 21. They screw into sockets exactly as if they were lamp bulbs. The fuse at A, Fig. 21, is of the "window" type. The window is mica and usually blackens when the fuse conductor burns out.

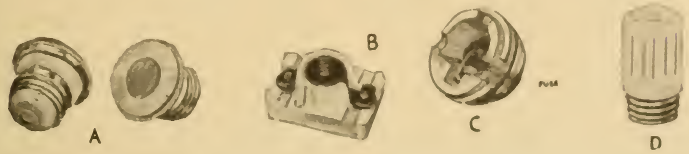

FIGURE 21

(38) Midget fuses, of the type found in automobile ignition systems, are used in sound equipment, as also are "grasshopper fuses" which in construction resemble a safety pin. The pin is held "closed" by a tiny pinch of solder metal, completing the circuit. When this melts with excessive current the pin flies open. There are also special cartridge fuses that contain a very thin fuse wire with a spring at one end; if the wire melts the spring pulls the broken ends apart. Such fuses, and grasshopper fuses, are used with very weak currents amounting to only a fraction of an ampere.

(39) The projection room should always have on hand an ample supply of fuses of all ratings and types used. When a fuse burns out the cause of the overload is not always easily determined. In the course of locating and curing the trouble a number of fuses may be inserted and burned out. A full supply of spares is accordingly necessary, and should be kept handy—the best place is right inside the cabinets or panels where they are to be used. Spare lengths of fuse wire should be kept on hand for replacement of "open" fuses. Open or link, fuses, incidentally, must be located inside a metal cabinet equipped with a self-closing door.

(40) Proper fusing is a matter of using fuses of the right capacity in every position. If the fuse be of a capacity unnecessarily close to the safety requirement it will burn out too readily, interrupting the circuit without

need. If it be too "large" it may not burn out until the limit of safety is past, so that it gives only inadequate protection. Ascertain the maximum current that should normally pass through any fuse socket, and fuse that socket just a little bit higher. For example, if the maximum current be 7 amperes, an 8-ampere fuse is too small, a 15-ampere is too large, a 10-ampere fuse about right.

(41) "Boosting" fuses is always poor practice, even where it is not dangerous. Consider a case of three different branch lines, each drawing 8 amperes from a common main. The current in the main is 24 amperes, and its fuses may be of 30-ampere capacity. The individual lines may be fused at 10 amperes each. Suppose further that through carelessness, intentional boosting, or lack of proper replacements, one of the branch lines is fused at 20 amperes. An overload in that line, raising its current to 15 amperes, will not burn out the boosted fuses, but will draw 31 amperes from the main, which should burn out the main fuses. Instead of one circuit being interrupted, three circuits will stop functioning. The cause of the trouble is thus made three times as hard to find. The projectionist may not even have light to work by. Moreover, the apparatus in the "boosted" line may be ruined before the current rises to the point of burning out the main fuse. Further still, a projection room fire may be started.

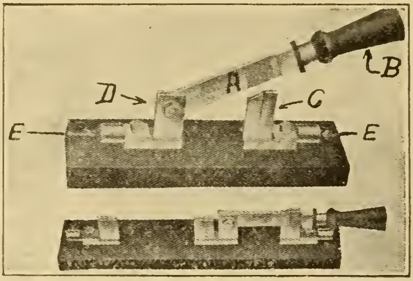

Figure 22

(42) It is good practice to mark on or alongside each fuse socket the rating (capacity) of the fuse to be inserted therein. It is even better to equip power fuse-

boards, which contain many fuses, with a blueprint showing all the connections and all the fuse ratings. Such markings or blueprints should always be modified immediately when any change is made in the wiring.

SWITCHES

(43) Fig. 22 illustrates (at A, B, C, D, E) a single-pole, single-throw knife switch, mounted on insulating material and equipped with lugs to which connecting wires are soldered. Below is shown a similar switch equipped with clips into which a cartridge fuse is inserted.

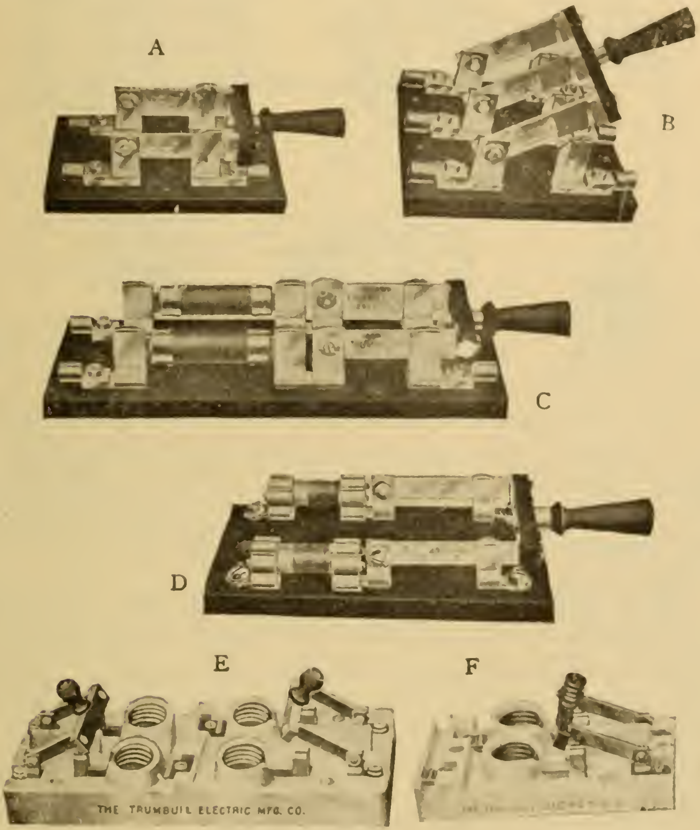

FIGURE 23

(44) Fig. 23 illustrates a number of types of single-

throw, double-pole knife switches, with and without fusing provisions, and (at B) a triple-pole throw knife switch.

(45) Fig. 24 illustrates a double-throw, double-pole switch, which can be used to connect a source of electrical supply to either of two circuits, and also can be connected to a circuit in such manner that the polarity is reversed by the action of the switch. (See Fig. 4, Page 31.) Both output circuits are fused.

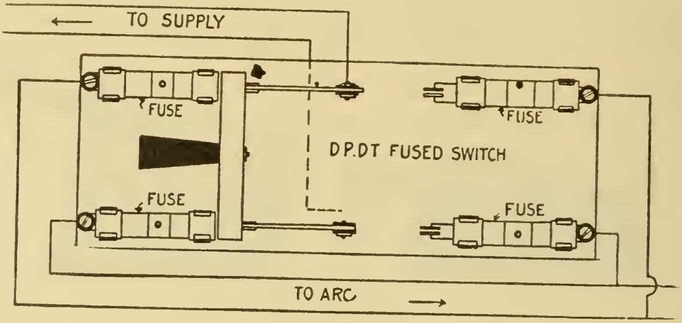

FIGURE 24

(46) Note that in all these illustrations fuses can be so connected that they are isolated from the source of power when the switch is opened. This is required by safety codes. When a fuse is to be replaced, the switches are opened, after which it is possible to work on the fuses without danger of electric shock.

(47) Double-throw knife switches should be mounted horizontally, so gravity will not tend to cause hinged blades to fall and close a circuit accidentally. Single-throw knife switches are preferably mounted horizontally, but if vertically mounted the switch clips must be uppermost, so that if the hinged blade or blades fall they will open the circuit, but cannot close it. These precautions are required by most safety codes.

(48) Fig. 25 is a spring-operated, fully enclosed, single-throw triple-blade switch. It has an insulated, external handle, which works on the switch blades through a strong spring, opening and closing the circuit

very quickly to prevent arcing over which would roughen or melt the copper of the blades and clips. Spring operated and enclosed switches are required by safety codes for certain types of service.

(49) Fig. 26 is a rotary switch, spring operated. It may have one or several blades, and may be single, double or multiple throw—that is, capable of effecting several combinations of electrical contact. The switch in the illustration is double-pole, double-throw.

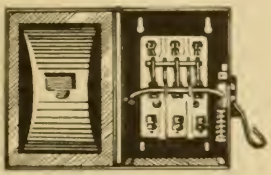
FIG. 25

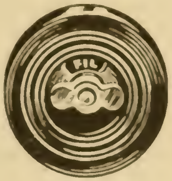
FIG. 26

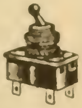
FIG. 27

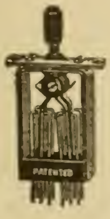
FIG. 28

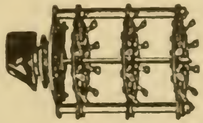
FIG. 29

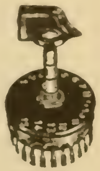
FIG. 30

(50) Fig. 27 illustrates a toggle switch, in this case double-pole, single-throw. Fig. 28 is four-pole, double-throw telephone-type toggle switch, of the kind used for sound switching. Figs. 29 and 30 are rotary switches. Fig. 30 is single-pole, but has 15 different "throws" or positions. Fig. 29 is triple-pole, 10-throw, and may be used for complex circuit switching in sound or television apparatus.

(51) Figs. 31 and 32 represent power switchboards. The heavy conductors running vertically down the center of each panel are called bus bars, supplying branch lines through switches and fuses. It will be noted that not all of the fuses can be disconnected from the source of supply

by opening switches. The reason why there are three instead of two bus bars in each switchboard will be made

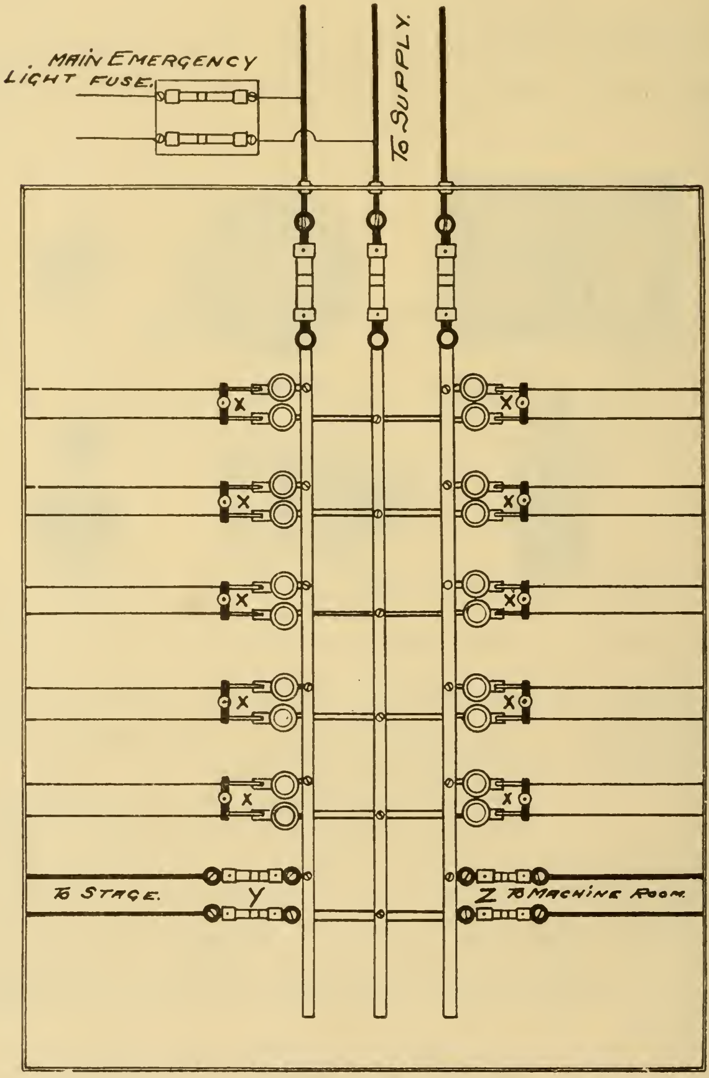

FIGURE 31

plain when commercial power circuits are described, further on.

(52) Switchboards are always mounted in metal boxes and enclosed with either metal or glass-and-metal doors.

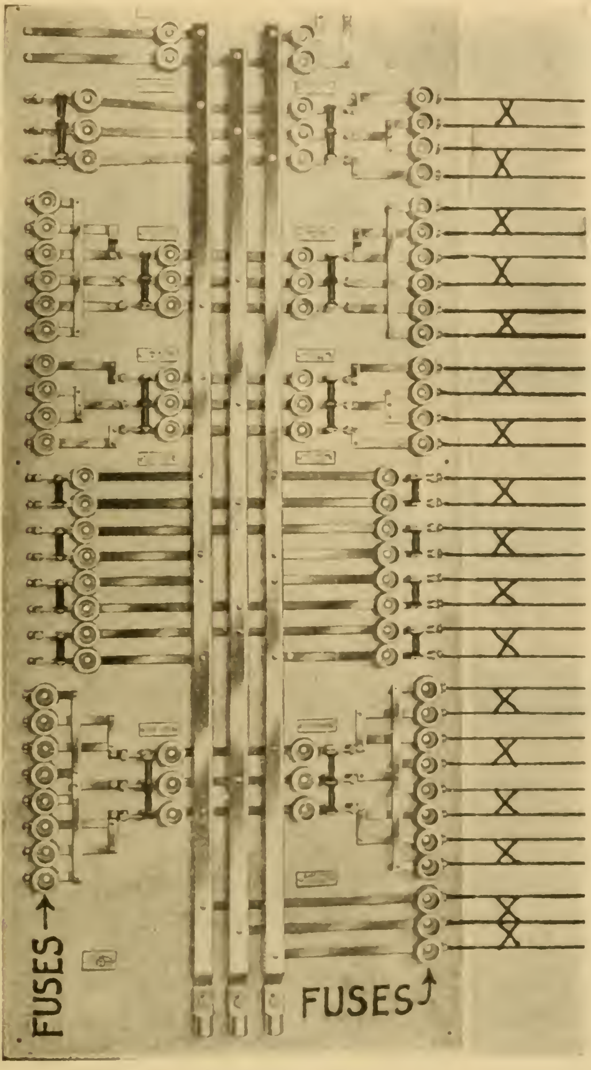

Figure 32

Resistors

(53) It is very often necessary to add to an electric

circuit a conductor of comparatively high resistance which is not intended to produce light, heat or power or to perform any similar function, but merely to provide resistance which will oppose current flow and produce a voltage drop. Special units, called resistors, are made for this purpose. They are available in an enormous variety of sizes and materials.

(54) A number of types of resistors are illustrated in Fig. 33. A represents a device wound of resistance wire (usually iron wire) on a ceramic core. Figs. 33 B and 33 C are devices of very similar construction, but coated with enamel which assists in radiating away the heat that is generated by the passage of current. Figs. 33 D, 33 E, and 33 F are of moulded composition which can be used to produce high resistance—as high as 10 million ohms or more. Fig. 34 illustrates the iron coils and grids, often so large that a separate resistance room is provided for groups of them near the projection room, which are used to provide a voltage drop required for operation of d.c. projection arc lamps. By contrast, the

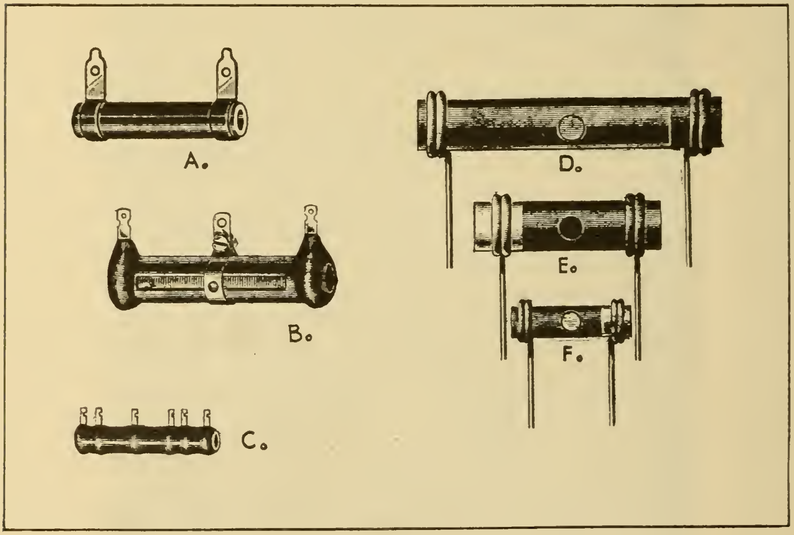

FIGURE 33

resistor of Fig. 33 F is half the size of a match. Resistors such as shown in Fig. 34 and in Fig. 33 A and 33 C are sometimes mounted in well ventilated metal coverings so they cannot be touched, because they often operate with their resistance elements very hot. The covering also prevents any inflammable substance from contacting these resistors. Such resistors are ordinarily used only for controlling the voltage of d.c.; they may be used on a.c., though only at very heavy waste of electric power as compared with the transformer.

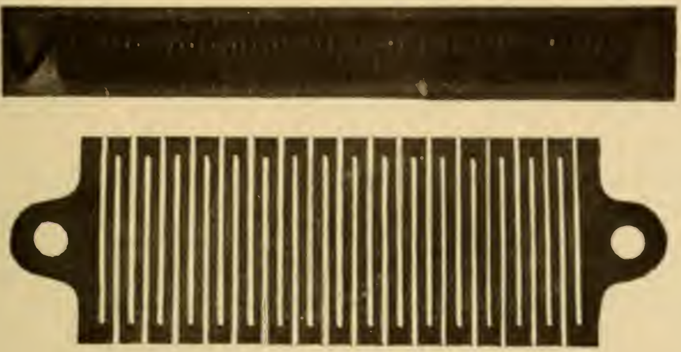

FIGURE 34

(55) Resistors are rated in terms of ohms, and of watts, the wattage rating referring to the power (I x voltage drop) which the resistor can carry without overheating to the point where it sustains damage. When replacements are ordered the wattage must be specified, as well as the resistance; and it is sometimes necessary to specify physical dimensions to make sure the replacement resistor will fit into the space allowed for it in a crowded amplifier or other apparatus unit.

(56) Small resistors, of the types D, E and F in Fig. 33, are often color-coded to show their resistance in ohms. Painting colors on them makes the information relatively permanent where printed figures might in the course of time become obscured by dust or be destroyed by heat. The code involves use of ten colors, each referring to one number. The colors and their numbers are:

Brown	1	Yellow	4	Violet	7	White	9
Red	2	Green	5	Gray	8	Black	0
Orange	3	Blue	6				

The color of the body of the resistor is considered first, then the color of the end and lastly the color of the dot or ring at its center. The dot or ring color does NOT represent a figure, but a number of zeros. Thus, if a resistor has a red body, a blue end and a brown dot, its rating in ohms is: (red) 2, (blue) 6, (brown) one zero—260 ohms. If the dot were green, five zeros would follow the first two figures, and the value would be 2,600,000 ohms. Some resistors are coded by three colored bands about their center, a broad band, a narrow band to one side, and still narrower band in the center of the broad band. These represent body, end and dot, in the order named.

(57) Fig. 33 B has an adjustable clip for contact, so the resistance can be varied as required. Fig. 33 C is a tapped resistor, affording a choice of six resistance values. It may be used as a voltage divider.

(58) Resistors are sometimes provided with multiple tap connections, and wired through a single-pole, multiple-throw switch (see Fig. 30) by means of which the resistance can be varied as required. It may then be called a rheostat—a rheostat being a resistance unit so constructed that its resistance can easily be varied.

(59) Rheostats of the types used in connection with sound and television apparatus are shown schematically in Figs. 35 A-35 E. Fig 35 A illustrates a simple rheostat connection. Fig. 35 B illustrates a three-point connection, which is preferable, since should the slider of Fig. 35 B lose contact with the coil of resistance wire, through the presence of dirt, loss of its spring tension, or other cause, the circuit will not be opened. All that will happen will be that the amount of resistance in the circuit will increase exactly as if the slider had been moved around to the left-hand end.

(60) It is important to avoid confusing the rheostat connection of Fig. 35 B with the potentiometer connec-

tion of Fig. 35 C. The potentiometer is an instrument by means of which any desired portion of the voltage drop across the resistance unit can be selected by moving the sliding contact—the pointer in the drawing. The desired voltage will appear across wires X and Y when the full voltage is applied across wires Y and Z. Potentiometers are used as volume controls. Volume control "faders" (see Chapter 20) work on the potentiometer principle.

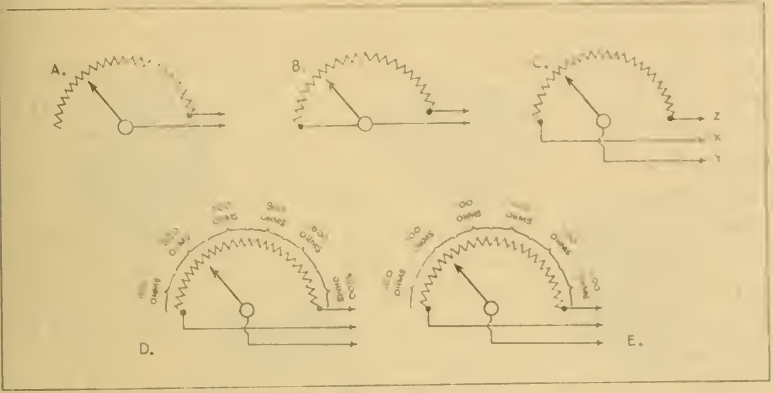

FIGURE 35

(61) A rheostat is sketched in Fig. 36 A. Fig. 36 B is a potentiometer, which also can be connected as a rheostat, of course. Fig. 36 C represents three potentiometers operated simultaneously by manipulating a single shaft. It is known as a "pad." The construction is such that by operation of the same shaft the resistance of one

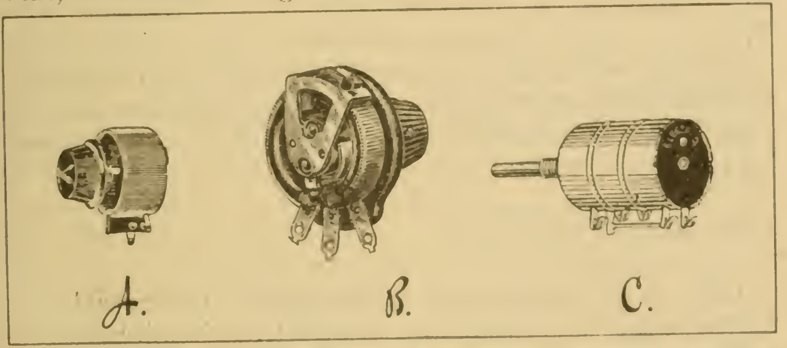

FIGURE 36

unit increases as that of other unit decreases. Pads are used for matching impedances in joining one a.c. circuit to another.

(62) Rheostats and potentiometers are rated according to ohmage, wattage and taper. Taper refers to the fact that the resistance does not always change evenly as the slider position is changed. If the change is uniform over all parts of the unit, the unit is said to have a "straight-line" taper (Fig. 35 E). Fig. 35 D represents a tapered unit, the resistance of which is not uniform. Replacements for such instruments should be ordered from the original manufacturer to assure proper taper, or the letter code associated with the unit (if the rheostat is marked thus) should be cited, together with the manufacturer's name. Otherwise the defective unit should be sent with the order to serve as a sample.

(63) All small rheostats and potentiometers do not have the physical construction shown in Fig. 36. Sometimes the resistance is provided by a plate or curved bar of composition material over which the slider moves, instead of by a coil of wire.

(64) Resistors, rheostats and potentiometers are intended to contain only pure resistance. Still, as will be understood, the wire-wound type, being built in the form of a coil, does possess some inductance, thought too slight to be important in the case of d.c. or low-frequency a.c. With the higher frequencies, however, particularly those associated with television apparatus, the inductance may be sufficiently important to make it inadvisable to try to substitute a composition unit for one of the wire-wound type, or vice versa.

Inductive Windings

(65) Inductance is sometimes added to electrical circuits merely for the sake of its effect on the circuit, and not in order to perform any external work through its magnetic properties. Inductors thus intended are called choke coils, inductive windings, reactors, impedance coils, retard coils, etc.—choke coil being the term most used.

They are rated in henries of inductance at a specified current (a "henry" being the practical unit of self-inductance) and sometimes also according to their d.c. resistance.

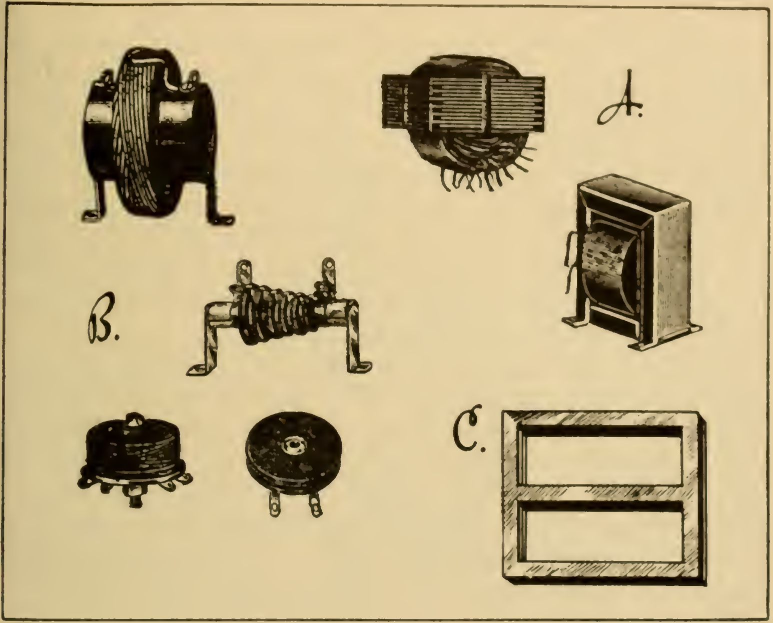

FIGURE 37

(66) Types shown in Fig. 37 A are low-frequency inductors, wound on iron cores. The iron consists of thin laminations, or plates, insulated from each other, and interleaved at the corners. The core often has the form shown in Fig. 37 C, with the coil wound about the center bar, the entire assemblage being clamped together by rivets or bolts at the corners, and often mounted in an iron casing which surrounds it completely.

(67) Iron-core chokes as a rule are not used at frequencies higher than audio frequencies. Radio and television inductors are shown in Fig. 37 B, wound on tubes of bakelite, ceramic or other composition. They are often referred to as "air-core" coils. Some windings used at

frequencies of 100,000 cycles or higher do however have iron cores, consisting sometimes of powdered iron, or of powdered alloys similar to permalloy.

TRANSFORMERS

(68) Two coils thoroughly insulated from each other may be wound on a core of the type shown in Fig. 37 C. Such a device constitutes a transformer. See Fig. 38.

(69) Alternating (or pulsating direct) current is supplied to one of the two windings. As the magnetic field rises and falls with fluctuation of the current strength, voltage is generated in the other coil. If the terminals of the second coil are connected to an external, closed circuit, the voltage so generated will cause current to flow in accordance with Ohm's Law.

(70) As was previously noted in connection with magnetic windings, when the current through them increases, the increase is opposed by a counter-voltage generated because of the expansion of the magnetic field, and when the circuit is opened the collapse of the field generates a reinforcing surge. This is transformer action operating upon the magnetic winding itself. It operates similarly upon any other conductor placed within the magnetic field.

(71) The coil of a transformer to which current is supplied is called the "primary" coil. The coil in which voltage is generated by inductive action is called the "secondary" coil.

(72) Transformers are referred to as "step-down," "step-up" or "1 to 1." If the voltage generated in the secondary winding is equal to the voltage supplied to the primary, the transformer has a one-to-one ratio. If the secondary voltage be greater than that of the primary, the device is called a "step-up" transformer; if the secondary voltage be less than that of the primary, the unit is a "step-down" transformer. The ratio of voltages is governed by the ratio of turns in the two coils of wire. The same number of turns of wire in both primary and secondary windings produce a 1 to 1 transformer. If the

secondary has more turns than the primary, the transformer will step up voltage applied to it, with a corresponding sacrifice of amperage. If the secondary has fewer turns than the primary, the transformer will step down the voltage—that is, the voltage that can be drawn from the secondary will be less than that applied to the primary, but the maximum secondary current will be proportionately greater than the primary current. If the secondary have twice the number of turns the primary has, the secondary voltage will be twice the primary voltage—amperage correspondingly less. If the secondary have ten times the number of turns, the transformer voltages will have a 10:1 ratio.

(73) In any transformer, which coil is primary and which is secondary does not depend on the construction of the instrument, but on the way it is connected. That coil to which current is supplied is the primary; that from which current is drawn is the secondary. A step-up transformer can be reversed and made a step-down transformer merely by changing connections to the coils.

(74) A transformer may have several secondaries, some step-up and others step-down, and thus may be made to deliver current to a number of different circuits at varying voltages and amperages. Such transformers are common in present day projection room equipment.

(75) A transformer may have only a single winding which is tapped (or has a connection at some point in its turns) making three connections to the coil in all. Such a device is called an autotransformer. The electrical arrangements are shown at center, Fig. 38. In the autotransformer there shown, if the part of the winding between A and B be made the primary, and the part

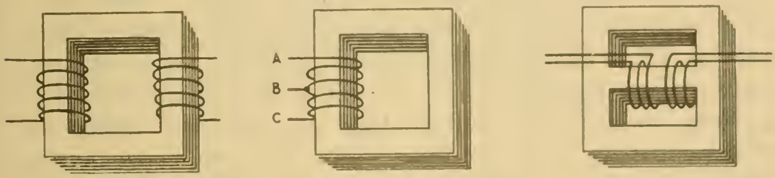

FIGURE 38

between B and C the secondary, the transformer will be of nearly one-to-one ratio. However, it can be otherwise connected. For example, the whole coil may be made the primary, by applying current at A and C, while B-C or A-C are connected as the secondary; or B-C may be made the primary and the whole coil be made the secondary, etc. The device shown at the right in Fig. 37 A may be a tapped choke coil (that is to say, an autotransformer) or a transformer with a number of windings, which may further be tapped to provide a great many possible voltage combinations. Such devices are sold with simple diagrams showing how connections can be applied to them to secure varying results as desired.

(76) Transformers are rated in terms of input and output (primary and secondary) voltages and currents—(or voltages and wattage) when they are to be used in power circuits. In sound (and television) circuits they may be further rated in terms of the impedance of each winding at some specific frequency.

(77) High frequency transformers cannot use laminated iron or permalloy (see page 83) cores. They sometimes have cores of powdered metal, or they may be air-core. They can be step-up, step-down, or 1:1, but in any case have very few turns of wire compared with a low frequency transformer. A typical radio-frequency step-up "coupling" transformer may have half a dozen turns of wire for its primary and 15 or 20 turns for its secondary. High frequency choke coils also have comparatively few turns of wire.

(78) Transformer action is the reason why metal cores of inductive windings are made in the form of laminations (thin insulated plates) or powder; never of solid metal. Iron, permalloy and so on are electrical conductors tending to act like transformer secondaries, hence so-called eddy currents are induced in the core, representing waste of power. Eddy currents are minimized by laminating choke coil or transformer cores, the plates being insulated from each other by thin layers of enamel, paint or other heat resisting non-conductor. The laminations are so placed with reference to the coils that the current

generated in them tends to flow from one lamination to the next, across the insulating layers, the presence of which reduces such currents to an unimportant value. A well-constructed transformer, with properly laminated core, may have an efficiency considerably in excess of 90%.

ELECTRICAL CONDENSERS

(79) Electrical condensers as manufactured today consist of two general types, commonly designated as paper and electrolytic condensers. These terms refer to the nature of the insulating layer in the device. There are also mica condensers (less common now than formerly) in which mica is substituted for paper.

(80) In its simplest form the paper condenser consists of a long strip of oiled or waxed paper, to both sides of which are glued some narrow strips of metal foil constituting the "plates." This strip of metal-coated paper is rolled up as tightly as possible, pressed into a cardboard tube and sealed, usually with wax. Wires in contact with the two strips of foil extend out of the cartridge. In another form of construction, shown in Fig. 39, sheets of insulating material and metal foil are interleaved; this type of construction is used for mica condensers.

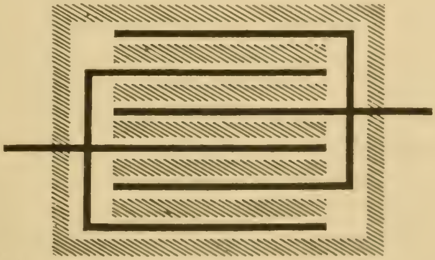

FIGURE 39

(81) The electrolytic condenser consists of a container, sometimes metal, sometimes waxed cardboard; a liquid or semi-liquid paste containing borax and boric acid

or equivalent chemicals, and a large piece of aluminum foil which has been rolled or crimped to occupy the smallest possible space. The liquid, which is a conductor, constitutes one of the "plates," to which external contact is made by means of a carbon rod or other suitable conductor. The aluminum is the other plate of the condenser. The insulating layer consists of an extremely thin chemical film formed on the aluminum by the action of the condenser liquid. The capacitance of any condenser may be increased if its insulating material can be made more thin. The chemically formed layer in the electrolytic condenser is far thinner than paper or mica, and small electrolytic condensers accordingly have very high capacitances.

(82) The common type of electrolytic condenser can be used with d.c. only, and must always be connected in correct polarity as indicated by markings on the device. The signs, "+" and "—" may be used to designate the terminals, or the manufacturer may prefer a simple color code in which the terminal to be connected to positive polarity is colored red and the negative terminal any other color. The insulating layer is formed in the factory by connecting d.c. to the condenser in proper polarity; if the condenser be wrongly connected the insulation will break down at once. That is why the device cannot be used with a.c., for which paper or mica condensers are required. Special forms consisting essentially of a double electrolytic condenser mounted in one case are made for use with a.c., but are not very common.

(83) The capacitance of condensers is measured either in micro-farads or micro-microfarads. The color code for rating resistors is often used for condensers, which are likely to be marked with three small colored dots and an arrow showing the order in which the colors are to be read. They have the same numerical significance as in the case of resistors (see page 80). Condensers also are rated in terms of the voltage their insulation will withstand, usually in terms of the *d.c.* working voltage. When used with a.c. the effective or "r.m.s." voltage to which they are exposed must, as already explained (see page

52), be less than 0.707 of the *d.c.* voltage for which they are rated.

(84) In replacing condensers, it is important that the replacement have a voltage rating which leaves an ample safety factor with reference to the circuit in which it is installed; in some circuits the capacitance must be exactly the same as that of the condenser which was replaced; in other circuits the replacement may have greater, but never a less, capacitance. Particular care must be taken to avoid the error of installing an electrolytic d.c. condenser as a replacement for a paper condenser in any circuit carrying a.c.

(85) When condensers are connected in parallel their capacitances add. Thus 4 microfarads in parallel with 2 microfarads make a total capacitance of six microfarads. The effect is exactly the same as if the plates of one condenser were given a larger area. When condensers are wired in series the effective capacitance is reduced. That is to say, the effect is the same as though the insulating layer of one condenser were made thicker. The formula for condensers in series is:

$$C = \cfrac{1}{\cfrac{1}{C_1} + \cfrac{1}{C_2} + \cfrac{1}{C_3}\text{, etc.,}}$$

but if condensers connected in series are all of equal capacitance it is only necessary to divide by their number. Two 6 microfarad condensers in series have an effective capacitance of 3 microfarads; three such condensers in series have an effective capacitance of 2 microfarads, etc. Note that condensers in series are figured like resistors in parallel, and condensers in parallel are figured like resistors in series (Pages 43-44).

TUBES

(86) Electrons seeking to move from negative to positive will flow not only through conducting metals, but also

through certain liquids, or through a vacuum and under some circumstances, through gases.

(87) Liquids and solutions which are capable of conducting current are at all times slightly ionized—that is to say, some of their atoms have lost an atomic electron or electrons, which same exist in the liquid in a free state, while the atoms that lost them, then called ions, become positive by reason of their loss. An ion meeting an electron in the liquid attracts it and becomes an atom again; while some other atom splits off an electron and temporarily becomes an ion. If two conductors charged at different polarities be dipped into such a liquid or solution, all free electrons will migrate to the positive conductor (the positive electrode, or anode); while the positively charged ions will move to the negative conductor, or cathode. There the ions will be neutralized by picking up an electron or electrons from the cathode and drift back into the solution, eventually to ionize again and repeat the process. The free electrons in the liquid, contacting the anode, enter it and continue around the circuit to the positive source. The effect is a flow of current through the liquid.

(88) If the two electrodes be sealed into a glass tube which has been filled with a suitable gas, normally current will not flow because gases ordinarily are not ionized. However, if the voltage between the electrodes be made sufficiently high, it will disrupt and ionize some of the gas atoms, the atomic electrons being torn away by the attraction of the negatively charged electrode; and the positive portion of the atom (the positive ion) being attracted to the cathode. The ions pick up new electrons at the cathode and go through the same cycle again; the whole process resembling conductivity in a liquid.

(89) Conductivity in gases may be greatly increased by assisting the ions to obtain electrons from the cathode. If the cathode can be made to give off or "emit" electrons of its own accord, the current through the gas at a given voltage will be much greater. Emission of electrons is promoted by heating the cathode to a high temperature. This is done by sealing a filament into a suitable tube,

coating it with insulating material, and coating that material in turn with the cathode. The filament is then heated by sending a current through it, the heat being transmitted through the insulating material to the cathode. In every substance at a temperature above absolute zero the molecules are in a permanent state of vibration, the energy of which is proportionate to their temperature. Increasing the temperature increases the molecular vibration of all substances. In the case of metals (particularly of certain metals and metallic oxides) high temperature vibration of their component molecules shakes loose atomic electrons with such force that those near the surface are ejected, or emitted.

(90) Fig. 40 shows a cathode and anode sealed into a glass envelope, as before described, with provision for heating the cathode by means of an insulated filament. Fig. 41 shows exactly the same arrangement, with the important exception that the filament and cathode are one and the same structure. Nevertheless there are two distinct circuits, the A and B circuit, in Fig. 41, just as in Fig. 40, and the current in each follows a path back to its own source.

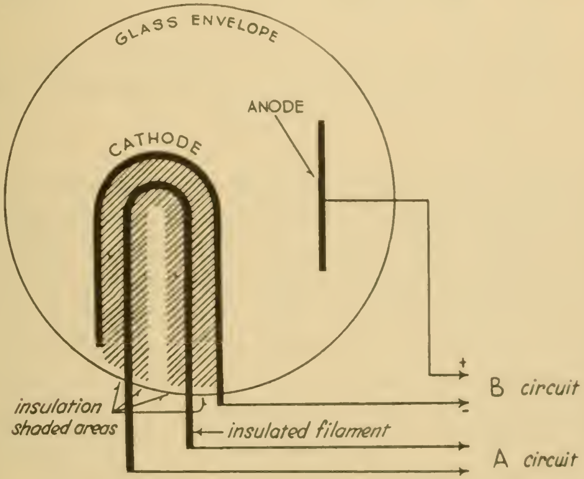

FIGURE 40

(91) Conduction through a vacuum has not yet been described. If there be no gas in the envelopes of Figs. 40 and 41, but if emission of electrons from the cathode takes place, those electrons will be attracted by the positively charged anode. A vacuum contains nothing, hence cannot hinder the electrons from being pulled to the anode. The resistance of a perfect vacuum is zero. The number of electrons arriving at the anode in a vacuum structure like Figs. 40 and 41 will be governed in part by the "emission resistance." That is to say, it will depend upon the number of electrons emitted, and other factors explained below. The total effect of all factors tending to limit the number of electrons reaching the anode is known as the anode impedance or plate impedance (the anode being sometimes called the plate). This is equal (Ohm's Law) to E/I, where E is the voltage difference between anode and cathode and I is the vacuum current.

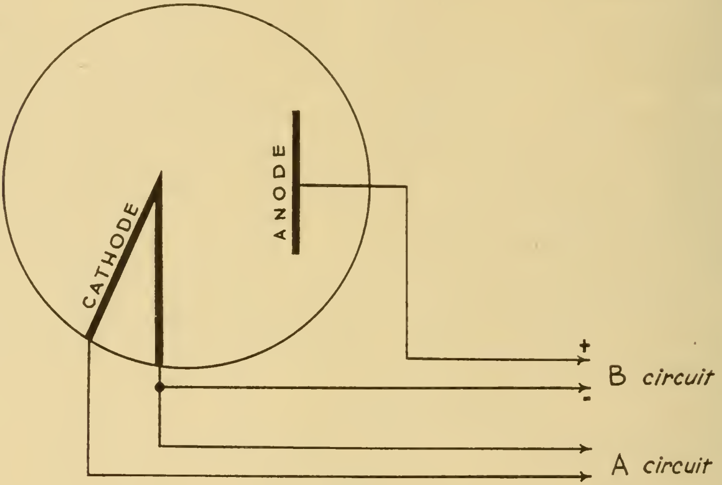

FIGURE 41

(92) In a vacuum tube of the type diagramed, the plate impedance includes the following influences: (a) The extent of emission from the cathode. (b) The fact that the cathode, having emitted electrons is left relatively positive by their absence. It is still negative as compared

with the anode, but is positive as compared with an electron, hence tends to draw back the emitted electrons, thus opposing the anode attraction. When an electron is first emitted it is much nearer the cathode than it is to the anode; the attraction of the cathode, although weak, is close by. If the electron be emitted with feeble velocity it will return to cathode. If it be emitted at high speed its momentum will carry it far enough from the cathode to allow the anode attraction to draw it the rest of the way across the tube. (c) There is a cathode space charge, formed by the cloud of electrons which have been emitted at weak velocity and are in process of returning to cathode. This cloud of negative electrons just outside the cathode surface tends to repel electrons just inside the said surface, that otherwise might be emitted; hence tends to repress emission. (d) An anode space charge resulting from what is called secondary emission. The anode is heated by the impact of the oncoming electrons, sometimes to a white heat. Both because of this increase in temperature and as a direct result of electron bombardment the anode produces emission. The electrons that leave it are soon dragged back by its positive charge, but in the interim they constitute a negative space charge surrounding the anode, which has some effect in repelling oncoming electrons of low velocity, driving them back to cathode instead of allowing them to complete their circuit through the vacuum.

(93) In a gas-filled tube the current at a given anode voltage is limited by the emission. However, there is no cathode space charge, this being neutralized by the positive ions which unite with its electrons as fast as they appear, therefore electrons leaving the cathode do not return to it again. The existence near the cathode of positive ions which have not yet been neutralized tends to promote emission. A gas-filled tube has much lower space resistance, or plate impedance, than a vacuum tube of the same structure.

(94) Tubes of the construction shown in Figs. 40 and 41 are strictly one-way conductors. Electrons can pass from cathode to anode, but not in reverse direction since

the anode is not an emitter (except to a slight extent when bombarded by electrons). If an alternating potential be connected to the B circuit of Figs. 40 and 41 current will flow according to Ohm's Law while the anode is positive but the B circuit will be open inside the tube whenever the anode becomes negative. Such tubes, both vacuum and gas-filled, are used in the projection room for the purpose of obtaining d.c. from an a.c. supply. They are said to "rectify" the a.c.—that is, convert it to d.c.—and are called rectifying tubes or more simply, rectifiers.

(95) Many vacuum tubes essentially the same as those diagramed in Figs. 40 and 41 are given the modified structure shown in Fig. 42. The additional element introduced between the cathode and the plate is called a grid. It consists either of metal mesh or a spiral of wire surrounding the cathode. Electrons passing from cathode to anode must move between the turns or through the meshes of the grid, and are greatly influenced by any charge that may be placed on the grid. The grid is located at that point between cathode and anode where electrons emitted with only moderate velocity can be made

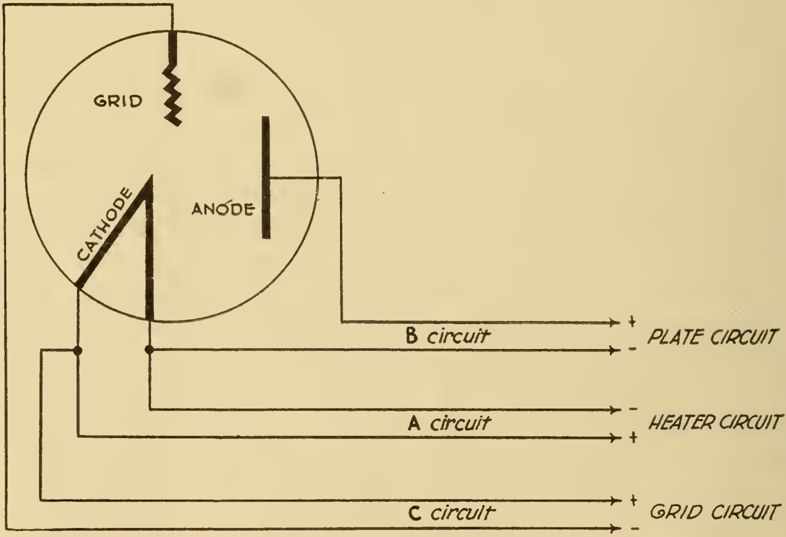

FIGURE 42

either to pass on to anode, or to return to cathode, by a very slight change in the voltage acting upon them. Because of the grid's location a very weak voltage applied to the grid by means of the C circuit may make an enormous difference in the number of electrons reaching the anode, that is to say, in the amperage of the space current. If the grid voltage be a.c. or fluctuating d.c. the space current will fluctuate in exact response to every slight change in grid voltage. The pattern of the grid fluctuations (which may perhaps resemble the bottom line of Fig. 8, page 36) will be reproduced in every detail, though on a much greater scale, in the plate current, with the result that that pattern has been amplified by the action of the tube.

(96) A tube of the type shown in Fig. 42 is called an amplifying tube of the three-element type, the three-elements being anode, cathode and grid. The cathode may be directly heated, as in Figs. 41 and 42, or indirectly as in Fig. 40. Another name often given this type of tube is triode, meaning it has three electrodes.

(97) The tube may have four elements and then is known as a tetrode. In such tubes an additional grid, called the screen grid, is mounted between the control grid and the anode. Since the anode and control grid are conductors separated by the insulation of a vacuum, they often act like a small condenser, with undesirable results that will be explained hereafter. To break up this condenser effect a screen grid is placed between them. The screen grid is positivly charged at a potential somewhat lower than the anode potential.

(98) The pentode or five-element tube in addition has a negatively charged suppressor grid which entirely surrounds the anode. Its purpose is to suppress secondary emission from the anode (page 93). In spite of its own negative charge, usually derived from connection to the cathode, the effect of this grid in suppressing secondary emission permits a greater flow of current through the tube.

(99) The beam power tube is a tetrode with a cathode so shaped, and so flanked by negatively charged vanes,

that the electrons are emitted from either side of the cathode in two concentrated beams, which same are directed toward appropriate recesses formed in the anode structure. This concentration of moving negative charges entering the recesses acts like a suppressor grid in inhibiting secondary emission and permitting the tube to pass a comparatively enormous current.

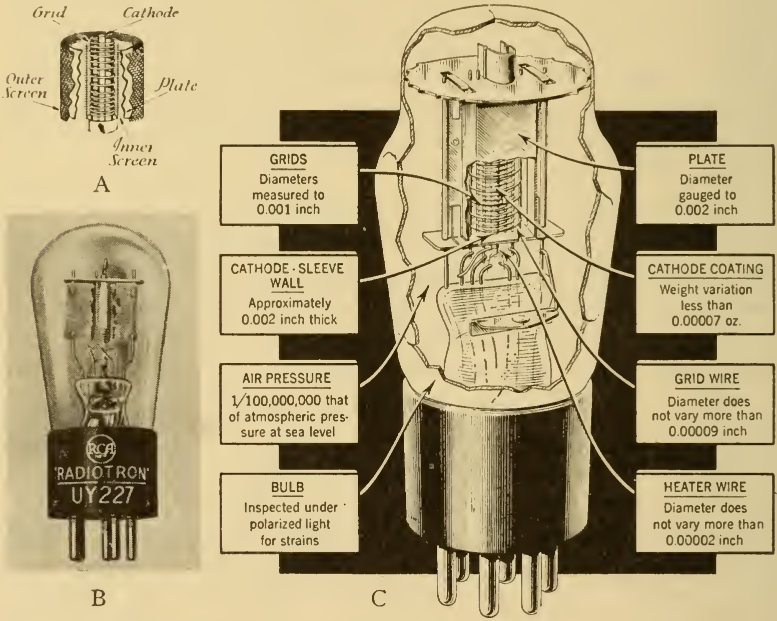
Grid
Cathode
Outer Screen
Plate
Inner Screen
A
RCA
RADIOTRON
UY227
B
GRIDS
Diameters measured to 0.001 inch
CATHODE - SLEEVE WALL
Approximately 0.002 inch thick
AIR PRESSURE
1/100,000,000 that of atmospheric pressure at sea level
BULB
Inspected under polarized light for strains
PLATE
Diameter gauged to 0.002 inch
CATHODE COATING
Weight variation less than 0.00007 oz.
GRID WIRE
Diameter does not vary more than 0.00009 inch
HEATER WIRE
Diameter does not vary more than 0.00002 inch
C

FIG. 43.—A is a diagram of electrode arrangement of screen-grid tetrode. B is an old-style triode showing electrode arrangement. Fine mesh is the anode; wire spiral is grid; white cylinder is cathode which is heated by hairpin-shaped filament buried inside it under an insulating layer. C is diagram of electrode arrangement of pentode.

(100) The structural detail of some common commercial types of tubes is illustrated in Figs. 43 A, 43 B and 43 C. The circuits in which they operate, and the results they produce, will be described in detail hereafter. Other tube types will be described in connection with the apparatus in which they function.

(101) Metal tubes differ from others only in that the surrounding envelope is metal instead of glass. Since

metals are somewhat more porous than glass, a special, unusually dense alloy has to be used to preserve the vacuum. (The outside air would seep in, though very slowly, through a thin envelope of ordinary steel.) Glass beads are fused into the metal envelope to serve as insulators through which are led the wires that connect to the internal elements. The metal envelope is not the anode. Except for serving as an electro-magnetic and electrostatic shield (warding off stray magnetic or static fields) it takes no part in the tube action.

(102) The photoelectric cell is a two-element tube, or diode, now invariably gas-filled, in which emission is not secured by heating the cathode, but by illuminating it—using a beam of light from an external source. For reasons still not clearly understood, thin films of certain metals of the "alkali" or "alkali-earth" families, particularly potassium and caesium, become moderately efficient in emission when illuminated, although they do not emit appreciably in the dark or when illuminated with light of the wrong color. A curved copper surface is coated with a thin film of photo-sensitive metal, which serves as the cathode of the cell. When light falls upon it, it emits electrons. An anode consisting of a thin copper rod is sealed into the same envelope. When positively charged from an external source, the anode attracts the electrons. The result is a device through which current will flow in exact proportion to the amount of illumination to which it is exposed. At any given illumination, the current in a gas-filled tube is greater, for reasons already explained, than it would be in a vacuum tube of the same construction and working at the same voltage. Hence photocells now are gas-filled. The gas used in modern photocells is generally argon.

LINE POWER SUPPLY CIRCUITS

Practical Questions

(For answer to each question see statement of corresponding number in Chapter V)

1. How is electrical power distributed through the theatre?
2. What four types of electrical power may be supplied to American theatres?
3. Describe the Edison, 3-wire, 110-220 volt d.c. system.
4. Can current be supplied to apparatus through the neutral wire of an Edison system?
5. Can current return to its source through the neutral wire of an Edison system?
6. If an Edison system be perfectly balanced, how much current flows in the neutral wire?
7. How is an Edison system balanced?
8. Why should an Edison system be balanced?
9. What are the advantages of the Edison system?
10. What important precaution must be observed in connecting apparatus to an Edison system, or in changing connections?
11. How is 220-volt apparatus grounded in an Edison system?

THREE-PHASE A.C. SUPPLY, PAGE 103

12. Is a 3-wire, 3-phase 110-220 volt a.c. system the same as an Edison system?
13. Describe a 3-wire, 3-phase, 110-220 volt a.c. system for power distribution.
14. Can 220 volts be supplied by any two wires of such a system?
15. What is meant by a delta connection? Star connection?
16. Where may delta or star-connected electrical arrangements be found in the projection room?
17. What is meant by balancing a three-phase, three-wire 110-220 a.c. volt system, and is it desirable?
18. What precautions with reference to grounds must be observed with a three-phase, three-wire, 110-220 volt a.c. system?

GROUNDS, PAGE 105

19. Is the grounding of conduit, and of casings of electrical machinery, ever required by safety regulations?
20. Why is grounding required?
21. What gauge wire is used for ground connections?
22. How is contact with earth achieved?
23. What is a ground clamp?
24. What inspection do ground connections need?

CHAPTER V

LINE POWER SUPPLY CIRCUITS

(1) Electrical power is brought to the theatre by supply lines which receive current from the street mains and run to a meter and fuse panel, usually located in the cellar. There the consumption of power is registered by a recording wattmeter. If there be more than one supply circuit, as is often the case, each is metered separately. From the meter panels branch lines, protected by conduit, extend throughout the theatre, conveying power to those places where it is to be used. One branch or feeder will run to the projection room switchboard (Figs. 31 and 32). If the theatre be supplied with more than one type of power (for example, both a.c. and d.c.) feeders will run to the projection room from each meter board and the projection room will be equipped with separate switchboards to receive each supply for distribution of the power to various equipments requiring its use.

(2) Power supplies to American theatres may be provided through any or all of the following: (a) 110 volt d.c. supplied through two wires; (b) 110 volt a.c., supplied through two wires; (c) 110-220 volt d.c. supplied through three-wire circuits; (d) 110-220 volt three phase a.c., supplied through three-wire circuits. A.C. may be furnished at 25, 50 or 60 cycles, according to the supply locally available. The switchboards illustrated, Figs. 31 and 32, are for three-wire 110-220 volt supply, either a.c. or d.c. This is shown by the fact that they are equipped with three bus bars, not with two. Power circuits more complex than any of those here mentioned exist, but are too rare in American theatre practice to justify attention in this work.

THE EDISON THREE-WIRE SYSTEM

(3) The three-wire, 110-220 volt d.c. system, known as the Edison system, is diagramed in Fig. 44. The

circles A, B, at the left represent power house generators, each of which delivers current at a pressure of 110 volts. They are connected in series, and since voltages in series add, the potential difference across the two outer bus bars, D and E, is 220 volts. But the voltage between either outer bus bar and the center bar, C (termed the "neutral") is, as the generator connections show, 110 volts. F and H are voltmeters registering 110 volts each; G a voltmeter registering 220 volts. The motor, M, is connected across 220 volts; I, J, K, L and N represent 110-volt apparatus, which may be lamps, motors or any other 110-volt equipment. The ammeter shown in series with neutral conductor C would be located in practice at the projection room switchboard so as to read all the current flowing through that conductor.

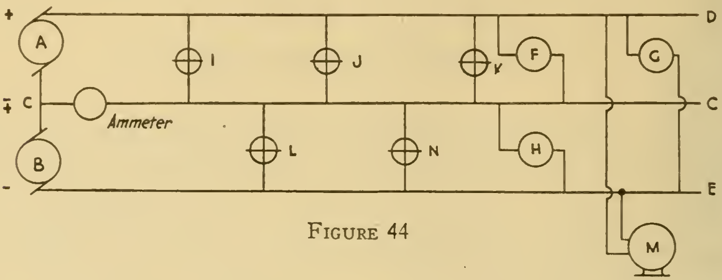

Figure 44

(4) Suppose there were no apparatus except J and L connected to the system sketched in Fig. 44. J and L are 110-volt appliances wired in series across a 220-volt supply, nearly similar to the series circuit in Fig. 11 (Page 45). The "neutral" wire, C, might not be needed. The two resistors in the series circuit of Fig. 11 both receive exactly the same amperage, since all current that flows in one must complete its path through the other. Fig. 44 presents a more convenient arrangement. Suppose L to have a resistance of 22 ohms, and J of 11 ohms, which would mean that by Ohm's Law L would pass 5 and J 10 amperes. Then 5 amperes from the bottom terminal of Generator B would flow through both L and J to conductor D, whereas the additional 5 amperes required by J would flow outward from the bottom terminal

of Generator A through neutral wire C to J, thus providing J with its 10 amperes.

(5) On the other hand, suppose L to have 11 ohms resistance and J 22 ohms. Ten amperes from Generator B then would flow through L, five returning through the neutral while the other five amperes complete their course through J.

(6) Neither of the two conditions just described is desirable. A three-wire Edison circuit should be, as far as possible, so balanced that no current flows in the neutral; that is to say, the current required by L and N in parallel should be as nearly as possible equal to the current requirement of all apparatus connected between wires C and D. If an exact balance can be obtained there will be no current at all in the neutral, and the neutral fuse might be removed without affecting the circuit. Under that ideal condition, the ammeter in Fig. 44 would read zero.

(7) To obtain the desired balance, connections are interchanged at the projection room switchboard. Suppose, for example, I and J each require 6 amperes and K, L and N each four amperes. Then the current between C and D is 16 amperes, while that between C and E is 8 amperes, hence eight amperes of balance current will flow in the neutral. If, however, K be disconnected from C-D and wired to C-E (placing K in parallel with L and N instead of as drawn) then K, L and N together will need 12 amperes, I and J together will need twelve amperes, therefore the system will be perfectly balanced, and the neutral current will be zero, which is a perfect condition. The 220-volt motor, M, has no connection with the neutral, hence the current through it has nothing to do with the balance of the system.

(8) Power companies encourage their customers to keep Edison 3-wire systems balanced because if their customers will do that the strain on their generators, A and B, will be more nearly equal and they can use a small wire for their neutral. Encouragement is sometimes given in the form of more favorable rates, or of penalty rates in cases of unbalance. The projectionist who neglects to balance his Edison 3-wire projection room circuit so far

as is possible, may therefore be loading his management with an unnecessary expense. (In modern power installations the two separate generators, A and B, may be replaced by a single, specially wound, double generator with a three-terminal output, but this does not make balance of the load upon it less important.)

(9) The Edison system affords the projectionist the advantage of supplying power at two different voltages to the same switchboard, thus simplifying projection room wiring arrangements. It enables the power company to supply two different voltages with considerable economy in the cost of wire. Moreover, considering only the 110-volt supply afforded by this system, the arrangement of Fig. 44 will need only ⅜ as much copper to deliver the same current as would be required by a single 110-volt, 2-wire system.

(10) One precaution of great importance to observe in a three-wire Edison system, whether it be in connecting new apparatus to it for the first time or in changing connections to secure better balance, relates to grounds. The neutral wire, C, is always grounded to earth at the power house; perhaps also at the theatre, therefore if L and N, Fig. 44, for example, are grounded to earth at their negative terminals, a short-circuit through earth will exist across Generator B. The short will be from the upper terminal of Generator B to earth, through earth to negative L or N, thence to the generator. The corresponding situation will exist with reference to Generator A if I, J or K be grounded at their positive terminals. There will then be direct connection through the earth between bus bars C and D, the only limit to the short being the resistance offered by this path. This point must be watched very carefully when balancing an Edison system. If K, as in the example previously given, is to be connected to E instead of D to assure better balance, K must first be checked as to its ground connections, if any. It may be found that the casing of whatever apparatus is represented by K is grounded to earth, either directly or through conduit connections, and that the negative side of K's wiring is grounded to K's case. If that is so the

terminals must be reversed, or such other changes made as may be required to ground the positive side of K's wiring to K's case after K has been disconnected from D-C and before it is reconnected to C-E.

(11) Similarly, neither connection to the 220-volt motor, M, may be grounded. If either is, either Generator A or Generator B will be short-circuited through the ground. If M needs grounding, its casing may be grounded, but only provided the same be thoroughly insulated from its wiring.

THREE-PHASE A.C. SUPPLY

(12) Three-phase a.c. 110-220 volt circuits must not be confused with three-wire Edison circuits. They resemble each other only that each has three wires and affords both 110 and 220-volt service.

(13) Fig. 45 A represents three a.c. generators, 1, 2 and 3, each producing a 60-cycle current at 110 volts. Their three outputs are each ⅓rd cycle out of phase with reference to the other. The external connections from all three generators, wired as shown, thus constitute a three-phase system. More commonly such systems draw current from a single generator equipped with three sets of coils to give the same type output as indicated in Fig. 45 A. Internal wiring of such three-phase generators is skeletonized at Figs. 45 B and 45 C.

(14) Note particularly that although Fig. 45 shows a 110-220 volt system, there is no pair of wires from which 220 volts can be drawn. Connection to wires A and C, Fig. 45 A, gives only 110 volts, since these wires are connected directly to the 110-volt output of Generator 2. Connection to any pair of wires, A-B, A-C or B-C, gives 110 volts only. Each pair is directly in parallel with the output of one 110-volt generator. However, when all three wires are connected to a motor or a transformer having internal wiring arrangements as at Fig. 45 B or 45 C, the effective overall pressure applied to that motor or transformer will not be 330 volts (as might be thought) but 220 volts.

(15) The arrangement of the generators in Fig. 45 A,

and of the internal wiring of Fig. 45 B, is called a delta connection, from the greek letter Δ. The arrangement of Fig. 45 C is called a star connection.

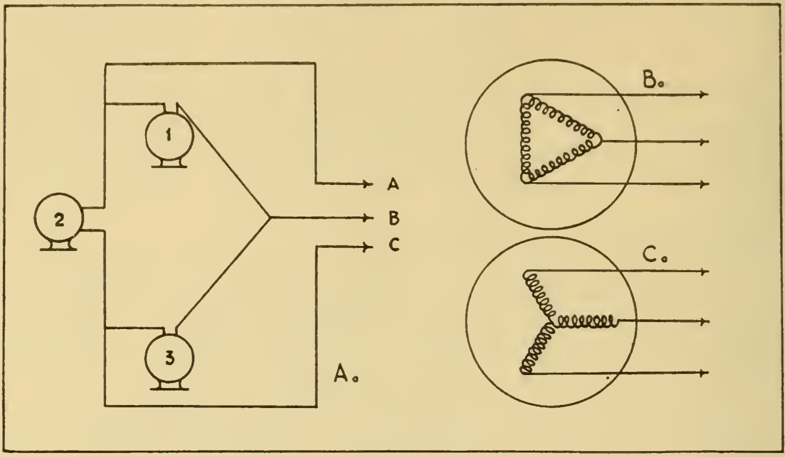

FIGURE 45

(16) Delta and star connections are found in the internal wiring of 3-phase, 220-volt apparatus. Single-phase, 110-volt equipment is connected to any two pair of wires, exactly as if each pair consisted of a common single-phase, 110-volt supply.

(17) It is desirable to balance the load between the three 110-volt circuits by making proper connections, or by changing connections at the projection room switchboard, so that each 110-volt pair delivers approximately the same amperage. Proper balancing equalizes the load upon the three generators of Fig. 45 A, or the three windings of Figs. 45 B, 45 C, and therefore is favored by power companies for much the same reason that balancing of an Edison 3-wire d.c. circuit is demanded. Both single-phase and three-phase apparatus may be connected at the same a.c. switchboard; single-phase equipments to any pair of wires, three-phase appliances to all three wires.

(18) It is necessary to be assured that none of the three wires is grounded in the projection room. If the

supply is drawn from a star-connected generator, or through a star-connected power line transformer, the centerpoint of the star may be grounded to earth at the power house or at the transformer location, in which case grounding any of the three wires will provide a short-circuit through earth. No apparatus connected directly to a system of this nature is ever grounded, except its casing when (and only when) the casing is thoroughly insulated from the power wiring.

GROUNDS

(19) The conduits of all power wiring, and the metal casings of many electrical appliances, are grounded to earth. In many cases grounding is required by safety regulations.

(20) Conduit, machinery casing, and other metallic objects located close to electrical currents or voltages tend to acquire charges by induction, eddy currents, or both. In the case of the projector mechanism, electrical charges may be built up by the friction of the moving parts. When two objects are charged at different potentials a spark may leap across between them, or from either of them to any third metal object, such as a water-pipe or a girder which is in contact with the earth. Sparking may take place through air or may take the form of a leakage current, or of intermittent sparking through any intervening insulation. The possibility of such sparking or leakage currents constitutes a serious fire hazard.

(21) Safety regulations in most communities require that conduit switch boxes, casings of electrical machinery, and other metal objects associated with the projection room's electrical equipment be thoroughly grounded to earth by a wire of medium or heavy gauge. Accumulated charges leak off to earth through this connection and in consequence all conduit, casings and so on are always at the same potential as the earth. The possibility of sparking is eliminated, and the only current leakage possible is that which trickles harmlessly through the ground wire.

(22) Contact with earth is seldom made directly, but generally through the medium of a water pipe, which of

course is in contact with the underground water-supply system, hence should be very thoroughly grounded. In some cases, however, it is not as thoroughly grounded as it should be because of rust formation in the joints of the pipe, which constitutes insulation between the different pipe sections. The water will not help much if it be very pure, since pure water—water with nothing dissolved therein—is not a very good conductor. The ions which provide conducticity in liquids come mostly from salts or other substances dissolved in the water rather than from the water, which itself furnishes conparatively few ions. Some regulations require that ground connections to a water-pipe must not be made just anywhere in the theatre, but at the point where the pipe enters the building from the street. Good grounds sometimes, with passage of time, deteriorate into poor grounds through corrosion of the pipe joints.

(23) Ground connection to a pipe, wherever located, is usually made by means of a special connector or clamp which can be made to grip the pipe very tightly so as to form and maintain a firm metal-to-metal contact. The ground wire is fastened or (more often) soldered to the connector. The pipe is filed very clean and bright before the connector is applied, and the bolt or nut by which the connector is wrapped around the pipe is drawn up to make the tightest possible contact. Some connectors are equipped with special, pointed bolts which pierce the surface of the pipe metal. The whole should then be painted or wrapped with insulating tape to keep moisture out. Two types of connectors or clamps are shown in Fig. 46.

(24) Ground connectors require periodic inspection to determine whether they have deteriorated. The soldered joint to the pipe connector is examined, and sometimes the connector is removed from the pipe to see if corrosion has set in underneath it.

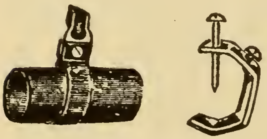

FIGURE 46

RECTIFIERS

Practical Questions

(For answer to each question see statement of corresponding number in Chapter VI)

1. Can projection rooms operate with a.c. power only, or do they need d.c. also?
2. What is meant by rectification? By "a rectifier"?
3. Is rectifier action mechanical or electrical?
4. Give an example of a uni-lateral conductor?
5. If a.c. be applied across plate and cathode of a rectifier tube, what kind of current will flow in the plate circuit?
6. Diagram and explain a simple tube rectifier circuit.
7. How can low voltage a.c. be converted to high voltage d.c.?

FULL-WAVE RECTIFICATION, PAGE 111

8. What is meant by a "half-wave" rectifier? Has it any disadvantages?
9. Explain what is meant by a full-wave rectifier, and how and why it works.

FILTERS, PAGE 113

10. Describe some filter circuits associated with a rectifier.
11. How are voltage dividers used in association with rectifiers and filters?
12. Are filters always used with rectifiers?
13. Are tubes the only rectifying devices in common use?

STACK RECTIFIERS, PAGE 116

14. Describe a rectifying "disc."
15. Describe the construction of a rectifying stack.
16. Under what circumstances should the adjustment of a stack holding bolt be altered in the projection room?

17. Are stack rectifiers adapted only to strong currents, to weak currents, or to both?
18. Describe and diagram a stack rectifier "bridge" circuit.
19. Does the bridge circuit give full-wave rectification?

Three Phase Rectifiers, page 119

20. Is there any ripple in the output of a stack rectifier bridge circuit?
21. What is the advantage of a three-phase rectifier?
22. Describe and diagram a three-phase stack rectifier bridge circuit.
23. Why are fans used in stack rectifiers?
24. What precaution against stoppage of the fan motor is built into many rectifiers?
25. How can a rectifier be controlled from a remote location?
26. Why are rectifier transformers provided with tap connections?
27. Describe the physical construction of a three-phase stack rectifier.
28. Where does the projectionist find specific information about details of the construction and wiring of apparatus, and where should he keep such information?

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CHAPTER VI

RECTIFIERS

(1) Power supply to most American projection rooms is a.c. but every projection room requires d.c. for operation of important items in its equipment. The majority of projection light sources are d.c. arc lamps. All sound amplifiers, without exception, require d.c., even those that are "a.c. operated." Only direct current can be used for the plates and grids of such tubes as shown in Figs. 42 and 43. Hence, alternating current supplied by the power line must be converted to direct current before it can be used for certain projection room purposes.

(2) Conversion of a.c. to d.c. is known as rectification. Apparatus that effects this conversion is usually called a "rectifier." One or more rectifiers will be found in every projection room supplied with a.c. power. In a.c. operated sound amplifiers the rectifier is built into the amplifier unit and constitutes an integral part of it.

(3) Rectification can be effected by mechanical means, by electrical means, or by a combination of both. A special form of mechanical rectifier, the "commutator," which is an integral part of d.c. generators, will be considered in another place (see Page 130). It is highly important in projection room practice, but the most common rectifying devices are electrical and the word "rectifier" usually is applied only to contrivances purely electrical in their nature.

(4) All electrical rectifiers depend for their action upon what is called uni-lateral, or one-way conductivity. An example of a one-way conductor of a type commonly used in projection rooms is given in Figs. 40 and 41. In those tubes, as was explained, electrons are emitted by the cathode and can pass through the vacuum or gas of the tube to the plate; but there is no appreciable emission of

electrons from the plate, and no flow of electrons from plate to cathode. The tube, therefore is a one-way conductor, insofar as its "B" or plate circuit is concerned, hence, if a.c. be connected with it as shown in Fig. 47, only d.c. will flow. The nature of the rectifying action is diagrammatically presented in Fig. 48.

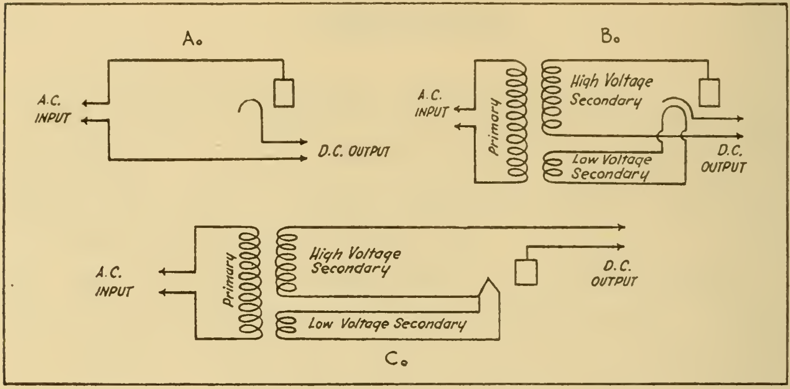


FIGURE 47

(5) Fig. 47 A shows the skeleton of a tube rectifier circuit, through which current can flow only in one direction. Since this circuit is wired to a source of a.c., current will flow in it only half the time—that is to say, while the plate of the tube is positive. During every other alternation of the a.c. source the plate of the tube will be negatively charged and no current will flow. Fig. 48 shows the result. In that diagram A illustrates ordinary line power a.c., B shows diagrammatically, by means of the dotted curves below the line, that each second alternation has been cut off by virtue of the uni-lateral or one-way conductivity of the tube, producing pulsating d.c.

(6) The skeleton arrangement diagrammed in Fig. 47 A is more completely presented in Fig. 47 B where the necessary associated arrangements have been added. It will be seen that the activating a.c. is not drawn from the power line directly, but through a transformer. This is the usual procedure; the transformer, having two secondaries, can deliver two different a.c. voltages. Low volt-

age (less than 110) is used to heat the filament. The plate is supplied by a secondary, which in some circuits also delivers low voltage—as low as 18 volts, perhaps. In others it delivers high voltages, up to as high as 1,500 volts in sound equipment; up to 100,000 volts in television equipment. Fig. 47 C shows the very similar arrangement used when the rectifying tube has a "direct heater" cathode of the type of Fig. 41.

(7) Figs. 47 B and 47 C illustrate another and different feature of the rectifier circuit which is quite as important in practice as its ability to convert a.c. to d.c. This is its ability to convert low voltage a.c. to high voltage d.c. The interrelated operation of tube and transformer, as shown in those diagrams, results in the creation of any desired d.c. voltage from ordinary 110-volt line a.c. The transformer converts low voltage a.c. to high voltage d.c., and the tube converts the high voltage a.c. to high voltage d.c. Many of the tubes used in sound amplifiers require plate potentials of several hundred volts, which same are easily provided through apparatus arrangements of the type here diagrammed.

Full-Wave Rectification

(8) As indicated in Fig. 48, only one-half of the a.c. supply is used by the rectifier arrangements thus far considered. The other half, consisting of alternations which charge the plate to a negative potential, meet practically infinite resistance in the tube. Hence, these circuits are called "half-wave" rectifiers. They have the disadvantage of producing a d.c. output which is characterized by a

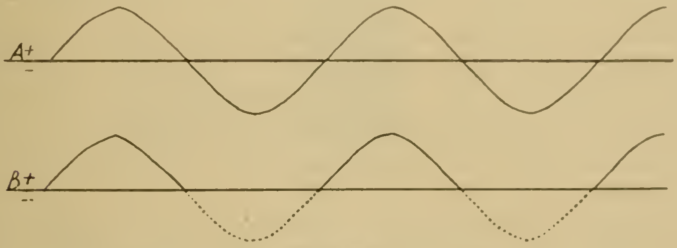


Figure 48

very heavy ripple, as Fig. 48 B indicates. The ripple can be "flattened" or smoothed out by a suitable filter consisting of inductors and condensers, but this process is helped if the d.c. output can be made more smooth to begin with.

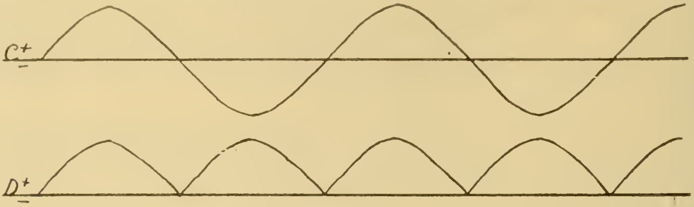


FIGURE 49

That can be done by modifying the arrangements of Fig. 47 so as to create what is called a "full-wave" rectifying circuit. A full-wave rectifier uses both halves of the a.c. cycle, thus giving the type of output shown at D in Fig. 49. Comparison with B of Fig. 48 will show that while

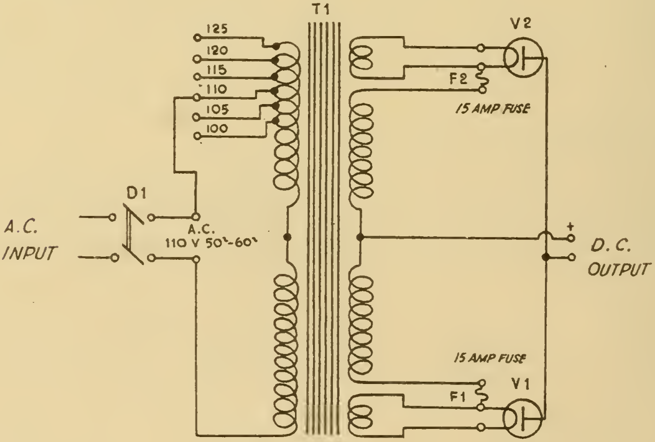


FIGURE 50

d.c. output of a full-wave rectifier is by no means free from ripple, it is much smoother than the output of the half-wave circuit.

(9) A full-wave rectifier is diagrammed in Fig. 50. It will be seen that the bottom half is an exact duplicate of Fig. 47 C. The top half also is the same circuit; but the two together, wired as shown, give the output of D,

Fig. 49. To understand this, consider any moment when the top half of the long secondary winding of Fig. 50 is positive. At that moment its top end will be more positive than its center-tap or mid-point. The plate of the upper tube, being connected with the mid-point through the output circuit, will be less positive than the cathode of the upper tube. In that tube, therefore, emitted electrons will not reach the plate, instead they will be drawn back to the more positively charged cathode. The reverse condition exists with reference to the lower tube, for the mid-point of the transformer secondary is more positive than the bottom of that secondary, which connects with the lower tube's cathode. Therefore, electrons will flow to the plate of the lower tube, upward and out through the external load, in again at the positive d.c. terminal and thence to the center-point of the secondary. At the next alternation, the bottom of the secondary becomes positive. The cathode of the lower tube becomes more positive than the plate of the lower tube. While that alternation lasts, no current flows through the space of the lower tube. The upper tube, however, conducts current while the top of the secondary is negative, electrons flowing to the plate, down and out of the diagram at the negative d.c. terminal, and through the external load to the secondary center-point. In each case electrons flow in the same direction through the external load. The output therefore is d.c. The output necessarily varies in strength, since it drops to zero between alternations, as indicated by Fig. 49. But with a full-wave rectifier there is never (as there is in a half-wave rectifier) any appreciable length of time during which output current remains entirely cut off, in evidence of which compare B of Fig. 48 and D of Fig. 49.

FILTERS

(10) Fig. 51 shows the rectifier of Fig. 50 equipped with filters. The d.c. output supplies five parallel circuits, four of which have their own filters. The filter circuit at lower left consists of inductor L-8, condenser C-7 and resistor R-7. Note that the condenser is an elec-

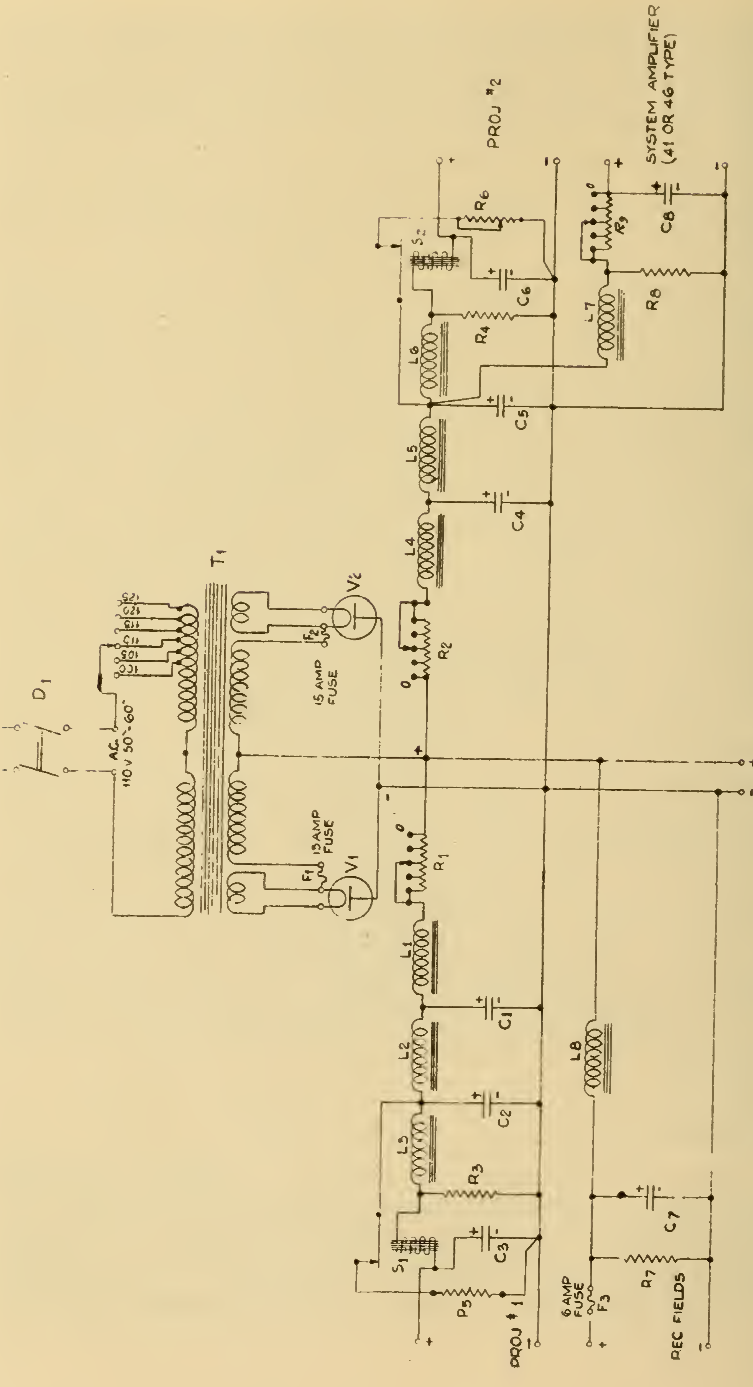


FIGURE 51 Tube-rectifier power unit supplying low-voltage DC.

trolytic condenser, as is indicated by the fact that its terminals are marked + and —. Directly above this is another circuit (more elaborately filtered) which contains L-1, L-2 and L-3; C-1, C-2 and C-3. R-1 is a rheostat (compare Fig. 35 B) by which the voltage output of this circuit may be adjusted. R-3 is the terminal or "Bleeder" resistor filter. S-1 is an electro-magnetic relay. As long as current flows in this circuit (completing its path through the external load), S-1 draws down the hinged bar shown just above it, out of contact with the arrowhead. But if the external circuit is for any reason opened, S-1 no longer carries current, the bar springs back and contacts the arrowhead, and current then flows (tracing positive to negative) from the left side of L-2 down through P-5. This is an automatic provision to protect the other circuits against any rise in voltage if the external load in series with S-1 be switched out of use. The student should find it instructive to trace the two similar, but not identical, filter circuits at the right side of the diagram. He will also note a 24-volt output at the bottom of the diagram, which is not filtered.

(11) Filter circuits which are similar in principle if not always in detail to those just explained are often, in practice, linked with voltage dividers (Fig. 11 E)—the direct current, after it has been rectified and filtered, is applied to a voltage divider from which a number of different d.c. voltages are drawn, according to the requirements of the amplifying tube elements to be supplied. The combination of rectifier, filter and voltage divider is particularly common in sound amplifiers. Examples of it will be given later when amplifier circuits are considered in detail.

(12) Rectified d.c. is not always filtered. Direct current supplying the field windings of loud speakers often is not, inasmuch as those windings are themselves inductances, hence do a good job of filtering their own input. Sometimes, however, condensers are associated with them, in which case they are, electrically speaking, filter inductors which serve simultaneously as the electromagnetic windings of loud speaker units. Occasionally

the filter circuit of an a.c.-operated amplifier is not equipped with a separate filter coil, but instead is wired to the speaker field winding, which then serves as a filter for the amplifier's d.c. supply; this arrangement is used in those monitor amplifiers that have electro-magnetic speaker units. Filters are seldom associated with rectifiers that supply d.c. to the projection arc lamp.

(13) Tubes are not the only rectifiers in common use. There are a number of metallic and partially metallic arangements which, for reasons not clearly understood, serve as one-way conductors. If copper be coated with a thin layer of copper oxide, the junction between the metal and the oxide can be made to exhibit unilateral conductivity. A layer of copper sulphide on copper does the same thing. A number of other combinations have been studied which act in the same way. Fig. 52 diagrams the essential arrangement.

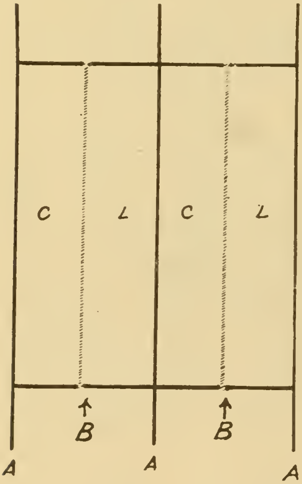


FIGURE 52.—C C are copper discs or washers; B B shows the copper oxide (or sulphide) coating; L L are lead discs or washers and AAA are metal "fins" to aid in heat radiation.

STACK RECTIFIERS

(14) Fig. 52 contains two rectifying "discs," labelled C, C, each being coated with an oxide or sulphide layer on one surface; two lead washers, labelled L, L, and three fins for radiating heat. A complete copper sulphide assemblage (in which the lead washers are replaced by discs of magnesium metal) is shown in Fig. 53. In such an assemblage a number of discs are stacked together and for that reason the device is often called a "stack" and it and its associated apparatus are known as a "stack rectifier."

(15) The construction of one form of stack rectifiers is shown, much enlarged, in Fig. 54. In the central part of that drawing the lead washers,

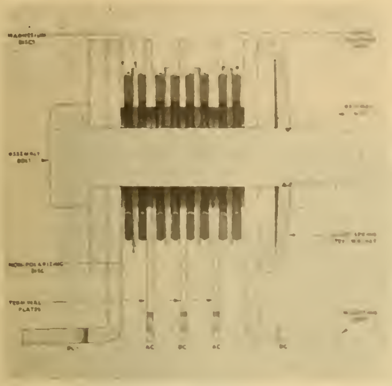


Figure 53

spacers, rectifying discs (copper coated with oxide on one surface) and cooling fins are spread apart for the sake of illustration, but in actual fact they are always tightly pressed together, as at the left side of that illustration. All of those parts are insulated from the holding bolt and are held in close contact by the pressure washer, spring washer and holding nut.

(16) The exact degree of pressure exerted by the holding nut is very critical. It must never be tampered with by the projectionist. Under no circumstances should the setting of that nut be changed, even if the rectifier work poorly. If the bolt be readjusted it may not work at all. In some factories these bolts are not set by hand because no workman can set them with sufficient accuracy; instead, sensitive machinery is used.

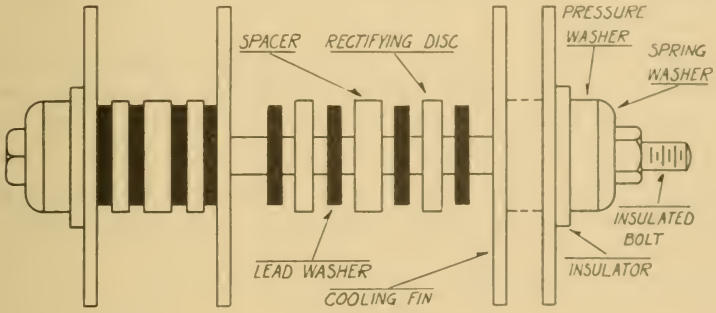


Figure 54

(17) Stack rectifiers are made in an enormous variety of sizes and capacities. Some common commercial types are shown in Fig. 55. The largest units in the photograph are of the type used to supply from 30 to 100

amperes to projection arc lamps. The smallest, seen at the lower left, is the activating element of the kind of rectifier often used with test meters, such as decibel meters. Its current-carrying capacity is limited to a few milliamperes.

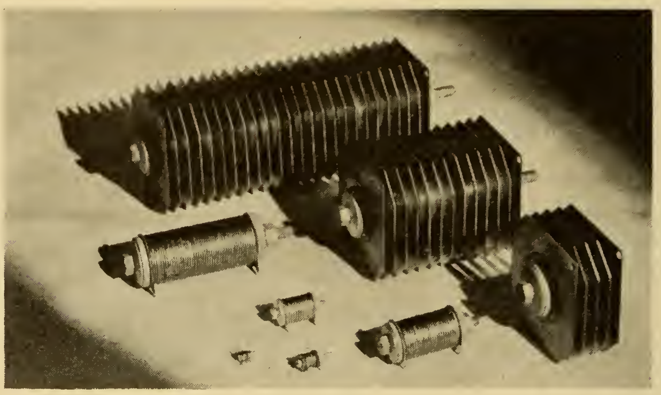


FIGURE 55

(18) Stack rectifiers are usually connected in a "bridge" circuit as diagrammed in Fig. 56, where each arrowhead-and-crossline symbol represents either one complete stack assembly (Fig. 55) or one section of such an assembly. The electrical arrangement is most easily understood by reference to Fig. 57. The arrowheads in that diagram do not represent direction of electron motion but direction of current flow according to the conventional idea of current moving from positive to negative. The circuit may be traced accordingly. When the upper a.c. wire is positive, trace through the upper right-hand

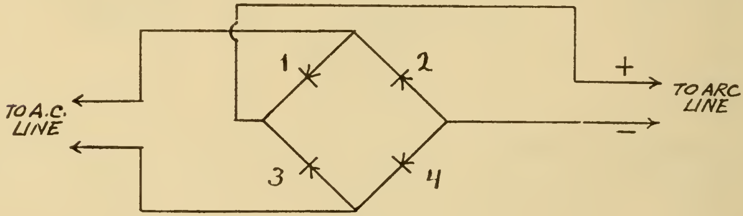


FIGURE 56

stack to the load, thence through the lower left-hand stack to the lower or negative wire. At the next alternation the lower a.c. wire will be positive, and the course of the current (from positive to negative) will be through the lower right-hand stack to load; then to the upper wire through the upper left-hand stack. In both cases the right-hand side of the load resistor is positive. Tracing similarly through Fig. 56 will show that the action there is essentially the same, and that the arrowheads in that drawing are drawn the same way—i.e., from positive to negative, or against the modern conception of direction of electron motion—in accordance with the conventional idea of current moving from positive to negative. Because of convention many electrical drawings, however modern, still show arrowheads pointing from positive to negative.

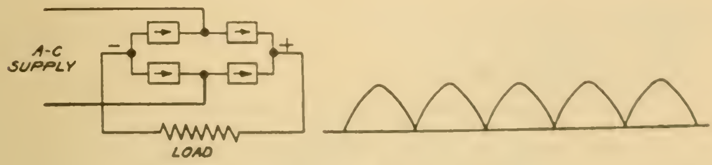


Figure 57

(19) Figs. 56 and 57 are full-wave rectifiers, because both alternations of the a.c. cycle are used. The type of output drawn from Fig. 57 is shown at the right of that illustration and is identical with that diagramed at D in Fig. 49. Use of the bridge circuit results in full-wave rectification.

Three-Phase Rectifiers

(20) In Fig. 49, and in the right half of Fig. 57, the output carries considerable ripple, though less than that shown at B in Fig. 48. Twice during each a.c. cycle the output drops to zero, but does not stay there for any measurable length of time. Still, if the input be 60 cycle a.c. there will be 120 points of zero output in every second. With the circuit of Fig. 58, however, ripple is far less; the minimum direct current occurring at any moment

varies from the maximum only by 14%. Fig. 58 is a three-phase rectifier, used with a.c. power lines of the type shown in Fig. 45.

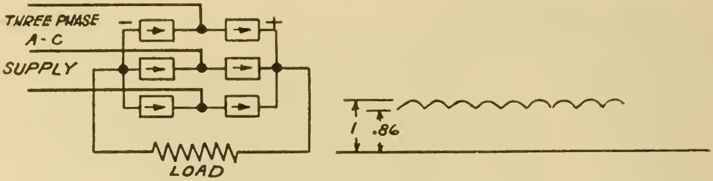


Figure 58

(21) Because the three currents in Fig. 45 are mutually ⅓ cycle out of phase with reference to each other, there is never a time Fig. 58's d.c. output drops completely to zero. At times when one phase is reversing its direction of flow (hence supplying no current to the d.c. output), the two other phases supply enough to prevent the output ever dropping more than 14% below maximum. Fig. 58 is a three-phase bridge circuit. Three-phase full-wave circuits are also used for tube rectifiers, with similar advantage of reduction in ripple content.

(22) Fig. 59 shows the whole circuit of a three-phase bridge rectifier for supplying d.c. to projection arc lamps. The upper portion of the drawing is occupied by the three sets of windings which constitute the power transformer. (The coils are here drawn like resistors.) Both primaries and secondaries of this transformer are delta-connected (Fig. 45 B). The six oblongs at the bottom of the drawing are the copper oxide stacks, wired in exactly the same way as in Fig. 58. The center of the diagram is occupied by the representation of an electric fan, and its safety relay.

(23) The fan is needed to keep the stacks cool at the high currents used for projection lighting. It sucks cool air upward past the stacks, and forces it out past the transformer coils. If it were to fail the stacks would seriously overheat and probably sustain either temporary or permanent damage. The fan is operated by a motor deriving its power from single-phase, 110-volt a.c. The

motor line is fused at the projection room switchboard. The d.p.s.t. switch shown at the right, center, in Fig. 59, is not located at the rectifier, but at the arc lamp. A relay (an electro-magnetic switch similar to S-1 of Fig. 51) is mounted within the rectifier and connected to the

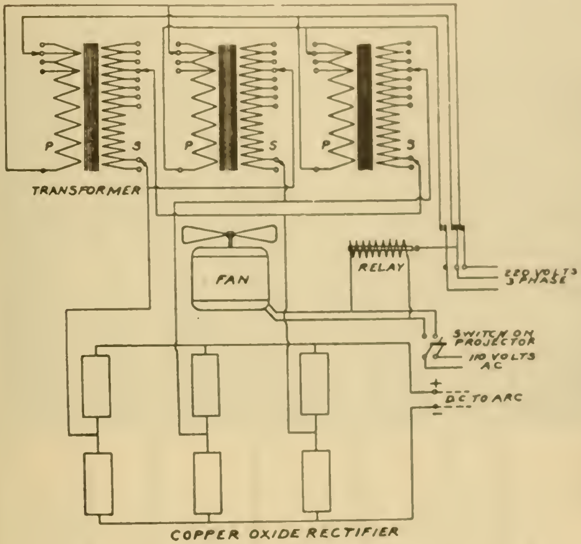


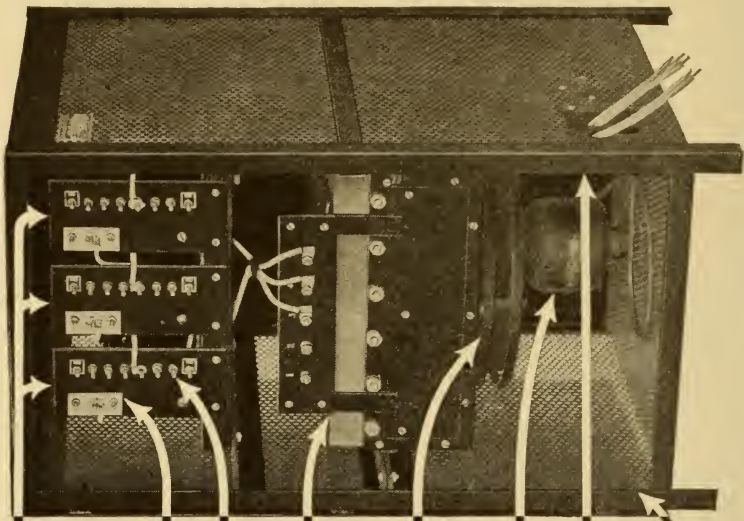
FIGURE 59

motor line. It is this switch which controls the 220-volt 3-phase supply to the rectifier transformer. When it is open the rectifier receives no current.

(24) Stoppage of the motor would almost always result in burning out the motor line fuses at the projection room switchboard. If this happened, the relay coil would no longer be energized, the 3-phase switch would open by spring action, and the stacks would carry no current and thus be protected against overheating.

(25) When the d.p.s.t. switch, located at the arc lamp, is opened in the course of routine operation, the relay is no longer energized, whereupon the three-phase line opens automatically. When the d.p.s.t. switch is again closed the relay closes the 3-phase switch and the rectifier functions. Thus the projectionist controls the action of the

rectifier from his working position alongside the projector, switching the rectifier on and off without going near it. In fact, rectifiers of this kind are sometimes



1. Multi-unit transformer for polyphase, full-wave rectification, delivering extremely smooth output.
2. Line voltage taps to permit adjustments for any line voltage from 190 to 250 volts.
3. Secondary taps to permit a wide range of adjustment in arc voltage and current to meet individual needs.
4. Copper Oxide Rectifier unit assembly. A permanent rectifying device, of proven reliability and safety, which will operate indefinitely without attention or replacement.
5. Blower system (patented) for forced ventilation of Copper Oxide Unit. By means of this blower system, the units are maintained at approximately room temperature. This feature will be appreciated by the projectionist.
6. Heavily constructed blower motor, equipped with over-size ball bearings, specially lubricated at the factory and capable of giving many years of service without further lubrication or attention.
7. Relays to provide protection in event of line failure and also permit operating the unit by remote control, if desired.
8. Substantial steel casing with attractive baked-enamel finish. Plain exterior, free from switches and controls. Nothing projecting which can be accidentally bumped or turned, causing an interruption of service. Compact design, cool and quiet operation permit installation in booth with safety.

FIGURE 60

located in attics or other out-of-the-way places. Commonly, there is one for each arc lamp, but sometimes a single rectifier is so designed that it can supply two arcs.

(26) The taps on the transformer windings are provided partly for the purpose of adjusting the device to low or high line voltage, as locally encountered, partly to allow for "aging." The resistance of the stacks changes somewhat during the first few months of use. In the course of that time, the transformer tap connections may have to be reset to keep the d.c. voltage supplied to the arc at proper value. After the aging period, there should normally be no occasion to readjust the tap settings.

(27) Fig. 60 is a photograph (with front panel removed) of an apparatus unit of the type diagramed in Fig. 59.

(28) In identifying the component parts, and more particularly the connection points, in such apparatus as that of Fig. 60 projectionists should refer to the literature of the manufacturer. This literature should be kept on permanent file in the projection room as long as the equipment is in use. Obtaining and filing exact information with reference to specific apparatus items is a matter of vital importance in projection practice.

GENERATORS AND MOTORS

Practical Questions

(For answer to each question see statement of corresponding number in Chapter VII)

1. Under what circumstances could a transformer be made to function with only smooth d.c. in its primary winding?
2. In what way does a generator resemble, and differ from a transformer?
3. What is the field coil of a generator? The armature coil?
4. Explain the principle of generator action.
5. Is there any a.c. in a d.c. generator; if so, where?
6. Explain the function and action of a commutator.

Physical Construction of Generators, page 131

7. Describe the construction of an armature.
8. Describe the construction of a commutator.
9. Describe generator field construction.
10. Why is there only a narrow air gap between the field poles and the armature of a generator?
11. Why is lubrication particularly important in connection with an armature?
12. How is the magnetic flux of a generator provided when the generator is first set into rotation?

Generator Circuits, page 134

13. What is a shunt-wound generator?
14. What is a series-wound generator?
15. What is a differential compound generator? A cumulative compound generator?

Motors, page 135

16. What will happen if, instead of being connected to a load, a generator is connected to a source of current?
17. Explain the action of a motor.
18. What is a motor-generator?
19. What are the electrical ratings of motor-generators used for projection arc lamp supply?

20. Describe a type of synchronous phonograph motor.
21. Describe a type of synchronous motor used for projection operation.
22. Why are synchronous motors used to drive projectors?
23. Are d.c. motors ever used to operate motion picture projectors?
24. How can the speed of d.c. motors be controlled?
25. What is the effect upon motor speed of increasing the field current? Why?
26. How can the speed of d.c. motors be automatically controlled?

Rotary Converters, page 139

27. Why must projection rooms manufacture a.c. if no a.c. line supply is available?
28. What is a rotary converter?
29. Explain the action of a rotary converter.
30. Where can the projectionist obtain constructional and circuit details of the particular make and model motors and generators he has to deal with?

Ballast Resistors, page 140

31. What is meant by ballast resistance?
32. Name the conditions that exist when shunt type generators are used.
33. What must ballast resistance do without over-heating?
34. What are the limitations of ballast resistance capacity?

To Parallel Compound-Wound Generators, page 141

35. Why is it necessary to use an "equalizer" between two compound-wound generators?
36. What is an equalizer?
37. If one cold compound generator is cut into the circuit of another already in operation, what happens?
38. Must the motor and generator be very carefully aligned?
39. How can the alignment of shafts be tested?
40. What is the effect upon motor generator sets if improperly handled?
41. What attention must a motor-generator have if it is to operate at a maximum efficiency?

Effect of Ballast Resistance, page 143

42. How much ballast resistance is permissible?
43. How does ballast resistance affect the flow of current?

44. What is the usual range of generator voltage above the arc voltage?
45. How does the arc feed affect ballast resistance?

OIL AND DUST, PAGE 144

46. What is the effect of oil on insulation?
47. Do dust deposits reduce generator efficiency?

WORN BEARINGS, PAGE 144

48. What serious condition is induced by worn bearings?
49. Describe the methods of checking bearings.
50. What tool is frequently used to test clearance between armature and pole pieces?
51. How can worn bearings be detected with a bar?

LUBRICATION, PAGE 145

52. How often should the motor be lubricated?
53. Will any ordinary oil suffice for a motor-generator?

BALL BEARING LUBRICATION, PAGE 146

54. What two common constituents of oil must be avoided in ball bearing lubrication? What must be done in the matter of selecting grease for ball bearings?

INSTALLATION SUGGESTIONS, PAGE 146

55. What first inspection should be made in a newly acquired generator?
56. Do all motors require a starting box?
57. What should be the capacity of the wires?
58. Does the Underwriter's rated capacity insure economical operation?
59. In selecting wire sizes is it necessary to provide for future increases in current consumption?
60. How is the voltage drop of a circuit calculated?
61. When is it wise to know the performance curve of a generator?

INSTALLATION, PAGE 147

62. Where should a motor-generator set be located?

63. What are the objections to placing the generator too far from the projection room?
64. Should there be plenty of clear space around the generator?
65. Can a generator be mounted on springs to absorb vibration?

BRUSHES, PAGE 149

66. What is important with regard to commutator brushes?
67. What is the correct method of fitting brush ends to the commutator surface?
68. What is best evidence that a commutator is in good condition?
69. How is the correct setting of the rocker arm (brush yoke) indicated?
70. What is the correct pressure in pounds for each square inch of brush surface?
71. If scale measurements show that brush pull varies, what condition is indicated and how can it be corrected?
72. How may brush pressure be measured by means of a rubber band?

CARE OF COMMUTATOR, PAGE 151

73. What results from a commutator sparking?
74. What deficient elements invariably cause trouble?
75. How should a commutator be brushed?
76. How can the commutator surface be cleaned right down to the copper?
77. After sanding a commutator what should be done before it is put in operation?
78. What is a commutator stone and how is it used?
79. After using a commutator stone what must be done?
80. Describe the method of making a commutator lubrication pad.
81. Should there be any sparking if the dynamo is not overloaded?
82. What causes sparking?
83. How are high commutator bars usually detected?
84. What does a slight motion of the brushes in the holder indicate?
85. How should you test for an out-of-round commutator?
86. Summarize the items on a commutator that need watching and correction?
87. Why do brushes stick in their holder? How can it be corrected?
88. Do commutator bars wear thin and require replacing?

89. Do soft commutator bars wear faster?
90. What does an overheated brush indicate?
91. Do worn bearings cause excessive sparking at brushes?
92. What occurs when an armature coil is short circuited?
93. How is a sprung (bent) armature shaft evidenced and what should be done about it?
94. What are the results of overloading?
95. Will a properly designed generator stand overloading? Is it good practice?
96. What would you regard as evidence of a weak field? How does it affect the motor?
97. What causes a weak field? How would you test for it?
98. If you discover excessive vibration in a new generator set, should it be refused?
99. What does a ring of fire around the commutator indicate? What should be done?
100. Where do you look for an open circuit in the armature circuits?
101. What will cause the armature to become overheated? What will happen?

Hot Bearings, page 158

102. If a bearing runs hot what should be done?
103. Should water be used to cool down a hot bearing?
104. How may a hot bearing be cooled down?
105. What must you avoid when bronze bearing runs hot?

Permissible Temperatures, page 159

106. If any part of a motor or generator feels warm, does this indicate something wrong?
107. What is the allowable temperature of machine parts?
108. How can the temperature of a machine part be measured?

CHAPTER VII

GENERATORS AND MOTORS

(1) Normally, a transformer will not work with only smooth d.c. in its primary coil, because with such current there is no change in the strength of the primary's magnetic field, and it is the *change* in field strength, not the field itself, which generates voltage in the secondary winding. However, if the mechanical construction of the device were made such that, (for example) the secondary coil could move, periodically changing its distance from the primary, and if a mechanical force were applied to produce such motion, the transformer would work with d.c. excitation. For this reason: the periodic motion of the secondary from a place where the field is strong to a place where it is weak, and vice versa, would have the same effect upon the secondary as if that coil remained motionless and the field strength varied.

(2) A device consisting of a primary and secondary coil, with both coils motionless, and variation in the strength of the magnetic field secured by variation in the exciting current, is called a transformer; whereas a device in which variation of field strength (so far as the secondary coil is concerned) is secured by physical motion, is called a generator.

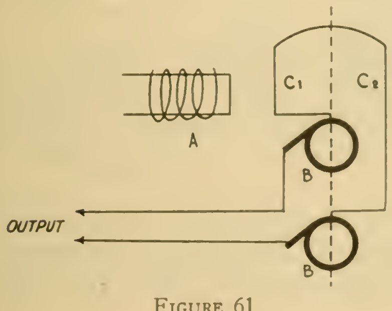


Figure 61

(3) In the case of a generator it is not customary to speak of primary and secondary coils. The windings that correspond to the primary of a transformer are called the field coils. The windings corresponding to the secondary, in which

voltage is generated, are called armature coils.

(4) The basic principle of generator action is diagrammed in Fig. 61, in which A represents an electromagnetic winding, C_1, C_2 an armature wire revolving on the dotted line as on a shaft, and B,B the "slip rings" through which contact is made with an external circuit. Assume that in the drawing as shown, voltage is generated in such direction that electrons move upward through C_1 and downward through C_2 to the lower slip ring. The lower slip ring will, therefore, be negative. In the course of one-half revolution of the coil, C_2 and C_1 will have changed places, but every other condition will remain the same; therefore in the next half-revolution electrons will be moving upward through C_2—which then will be nearest the magnet—and downward through C_1, and the upper slip ring will be negative. The generator thus produces alternating current, in spite of the fact that the current exciting field coil A may be d.c.

(5) All d.c. generators used in the projection room operate on the principle of Fig. 61, and all produce alternating current in their armature windings in spite of the fact that direct current is drawn from them. The d.c. is obtained by means of a mechanical rectifier, a very simple device, which is substituted for the slip rings. It is called a commutator. Its principle of action is diagrammed in Fig. 62.

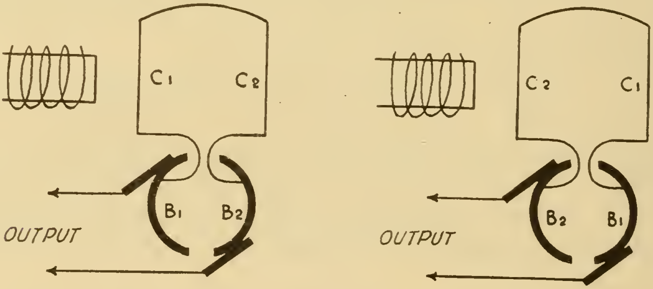


FIGURE 62

(6) In Fig. 62 the place of two slip rings located side by side on the same shaft is taken by a single revolving contact split into insulated segments, B_1 and B_2. The

segments revolve with the armature. Together with their insulation they constitute a "commutator." In the left-hand drawing of Fig. 62, C_1 is nearest the field coil. Assume the direction of the generated voltage to be such that electrons move upward through C_1, downward through C_2 and out to the external circuit through B_2 and the bottom output wire. The bottom output wire then is negative. The right-hand drawing of Fig. 62 shows conditions one-half revolution later. Electrons now move upward through C_2, downward through C_1 and out through B_1, but they still move outward through the bottom output wire, and the bottom output wire is still negative. Because of the action of the commutator, d.c. is drawn from the generator in spite of the fact that a.c. is generated in its armature coil.

Physical Construction of Generators

(7) An armature coil seldom consists merely of a single turn of wire as it is shown, for the sake of simplicity, in Figs. 61 and 62. The coil generally consists of several turns, as indicated in Fig. 63. Not only, as a rule, does each coil consist of several turns, but the armature is built up of a number of these multi-turn coils, as indicated in Fig. 64. The coils are wound upon the armature core, which is a cylindrical piece of iron often laminated for the same reason transformer cores are laminated (see Page 86), and is slotted (provided with surface depressions) in which slots the wires are wound.

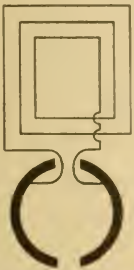


Figure 63

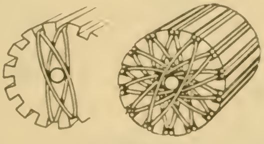
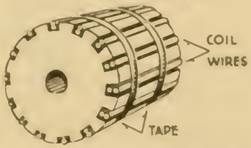


Figure 64

Figure 65



The wires are held in the slots by armature tape, which is wrapped around core and slots. (See Fig. 65). The tape keeps the wires from being thrown out of the slots, which would otherwise occur under the action of the centrifugal force to which they are subjected when the armature rotates at high speed. The electrical arrangement and connection of the coils depend upon the type of "winding." Armatures are wound in several different ways, according to the design of the generator. The projectionist should know how the coils in the particular armature he is using are wound, and how they are interconnected with each other, because he will need this information if he ever has occasion to test through one with a meter in searching for an open circuit, short circuit or ground. He may obtain that information from the manufacturer of his equipment.

(8) The commutator consists of a large number of copper segments, embedded in insulation and separated from each other by mica spacers. The sliding contacts resting on the commutator, through which current is transmitted to the external circuit (see Figs. 62 and 68) are called "brushes," made of carbon. The contact surface of a brush must be carefully curved to match the curvature of the commutator. The brush is pressed into firm contact with the revolving copper segments by means of spring tension. It is very important that this tension be exactly right. (See Page 142.)

(9) The electro-magnet shown in Fig. 61 is actually a horseshoe magnet, the true skeleton arrangement of which is shown in Fig. 66. The direction of the current through the coils is so arranged that if magnet A of Fig. 66 causes electrons to move upward through C_1 magnet B

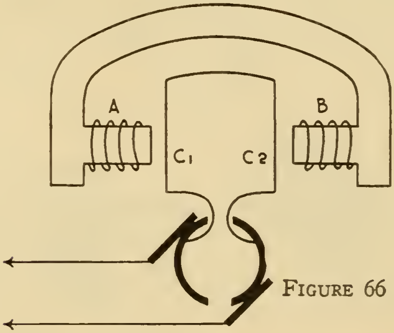


FIGURE 66

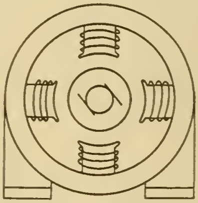


FIGURE 67

will cause electrons to move downward through C_2. The voltages generated in the armature by the two magnetic poles reinforce each other. There may be four poles, as in Fig. 67, or more than four, in large machines.

(10) As Fig. 67 shows, the entire frame or outer casing of the generator may constitute the core of the field windings. The field poles themselves, and often the core of which they are physically a part, are given laminated construction for greater efficiency. Also for reasons of efficiency the faces of the field poles are curved to match the curvature of the armature, and the spacing between the armature and the faces of the field poles is reduced to a minimum. The iron core of the armature forms part of the path of the magnetic flux, and since iron is a better conductor for the flux than air, it is desirable to have the air gap between armature and field pieces as short as possible. In well constructed machines this gap is so small that it is not possible to slip a piece of moderately thick cardboard between the armature and the faces of the field poles.

(11) The central shaft of the armature is supported by bearings at either end of the machine. Because of the closeness of the spacing between armature and field pieces, appreciable wear in the bearings may permit the armature to rub against the field pieces as it revolves. If this should occur the armature tape (Fig. 65) may be abraded and the armature wires raised out of their slots by centrifugal force. Bearings must be very carefully lubricated

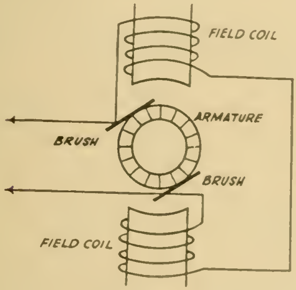


FIGURE 68

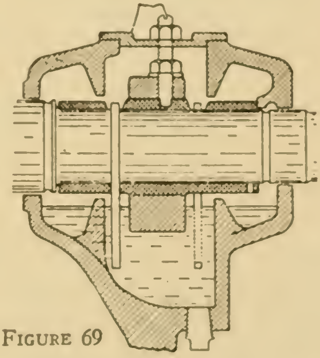


FIGURE 69

to minimize wear. Sleeve bearings are often provided with an oil reservoir and an oiling ring. See Fig. 69. The ring rides on the armature shaft in a slot provided for it, and extends down into the oil well. As the shaft revolves, the ring rotates, carrying oil up to the top of the shaft.

(12) The field windings of generators used in projection are excited by d.c., which is obtained from the generator itself. When the generator is put into action, and the armature begins to revolve, only a very weak current is produced because there is not as yet any d.c. in the field windings; the only current in the armature is that resulting from the extremely feeble "residual magnetism" of the poles. The iron core does not demagnetize completely when current no longer flows in its coils. It retains a slight "residual" magnetic power. This is enough to produce only a minute armature current. But since the field windings are in electrical contact with the armature coils (as will be explained) a very weak current flows in the field windings, providing a small degree of electrical excitation, and thus producing a stronger armature current. This stronger current increases the field excitation, with the result that a still stronger armature current is created. The process continues until (in a few seconds) the machine is working at normal capacity.

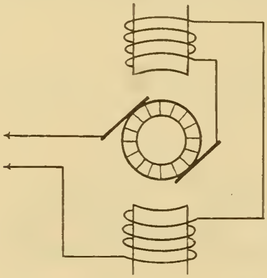


FIGURE 70

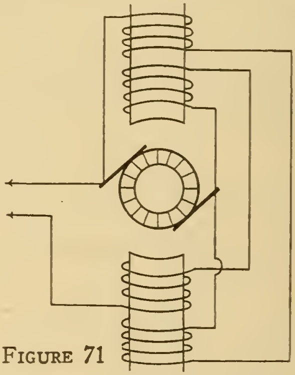


FIGURE 71

GENERATOR CIRCUITS

(13) The field coils may be connected with the arma-

ture output as in Fig. 69, which shows what is called a shunt-wound generator, because the field circuit is in shunt, or parallel, with the armature circuit.

(14) Fig. 70 shows a series-wound generator, the field circuit being in series with the armature—and also with the external line, instead of in parallel to them.

(15) The field poles may carry two different windings, as shown in Fig. 71, where each pole has both a series and a shunt winding. A generator so connected is said to be compounded, or is called a compound generator. There are two different kinds of compounding, differential and cumulative. In the former, the direction in which the field wires are wound is such that the magnetic fields created by the series and shunt windings tend to oppose each other; in the latter they reinforce each other. (See Fig. 72). Because its output gives maximum steadiness to the projection arc, the cumulative compound generator is favored in projection room practice.

Motors

(16) All of the generators referred to above are motors as well as generators. If their armatures are made to rotate by application of an external mechanical force they operate as generators, supplying current to their output terminals; if, on the contrary, current from an external source be applied to their terminals, their armatures will rotate and the machines will act as motors.

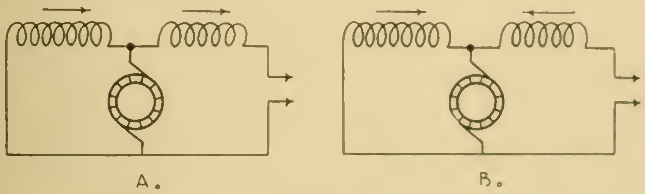


Figure 72

(17) Refer to Fig. 62. At the moment when current from an external source is applied, the relation of the magnetic forces developed by the armature wires and the field winding may be such that C_2 is attracted toward the

field coil and the armature revolves until C_2 is as close to the field as possible. But the commutator rotates with the armature and when C_2 comes closest to the field coil the commutator action reverses the direction of armature current, with the result that C_2 is then repelled by the field, and C_1 attracted to it. Thus the armature continues to rotate, and the device functions as a motor as long as it is supplied with current.

(18) Motors for alternating current are of more varied construction and design. Fig. 61 is a skeleton drawing of the type of a.c. motor commonly used in projection to operate d.c. generators of the type of Fig. 62. Both motor and generator are often mounted on the same base, sometimes having a common exterior casing; occasionally the motor armature and the generator armature are built on the same central shaft. In other designs, motor and generator have separate shafts which are linked by a coupling (Fig. 73), so that when the motor armature rotates the generator armature must revolve in unison therewith. This combination is called a "motor-generator," and is extensively employed to transform a.c. to d.c. at suitable voltage.

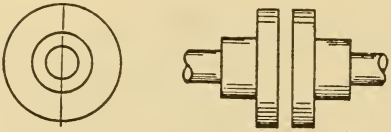


FIGURE 73

(19) Projection arc supply motor-generators are driven by either 110-volt single phase or 220-volt three phase a.c., or other alternating currents according to the nature of the local supply. The generator produces from 40 to 80 volts and may have capacity to produce from 30 to 200 amperes, as needed.

SYNCHRONOUS MOTORS

(20) Synchronous motors are a.c. operated and maintain a constant speed, regardless of any ordinary variations in the mechanical load imposed upon them. Synchronous motors of small size are used to rotate the turntables of the electric phonographs which, in the modern projection room, serve to supply incidental music.

One type of synchronous phonograph motor has no brushes. Its armature consists only of a metal disc. Alternating current in the field windings generates eddy currents (Page 86) in this disc; the direction of the eddy currents is such that the portion of the disc nearest a field piece is repelled and a more remote portion attracted; hence, the disc revolves. Since the eddy currents in the discs are generated by a.c. excitation of the fields, the rate of rotation is strictly controlled by the frequency of the applied current and cannot vary. If excessive load is applied the motor stops; it cannot slow down.

(21) Synchronous motors used to drive the projector mechanism may be regarded essentially as being transformers which have secondary windings so mounted that they are free to rotate. Current is induced in the armature windings by virtue of a.c. flowing through the field coils; the magnetic reaction between armature and field currents causes the armature to rotate. The speed of rotation is controlled by the frequency of the applied current. A kind of "squirrel cage" construction, consisting of copper bars embedded in the pole faces and connected at their ends, helps steady the rotation. For this reason such motors are sometimes known as "squirrel cage" motors. Polyphase motors of this type are self-starting, but the single-phase motors used for projector operation would not be, except for the addition of a brush connection to the armature. The alternating current supplied to the armature through the brushes is not in phase with the a.c. generated in the armature by induction, hence a motor of this kind is further distinguished by the title of split-phase motor.

(22) Synchronous motors are used for projector operation (also frequently for phonographs) because of the need for constant speed to assure good reproduction of sound. The frequency of commercial power lines is very accurately regulated, and hence can be trusted to assure constant speed operation of all motors which depend upon the frequency rather than applied voltage for speed control. Voltage is still rather poorly regulated in commercial supply lines.

(23) Some theatres are located where alternating current is not available, therefore cannot use synchronous motors driven by the supply line, but must rely on d.c. equipment. Projectors in such theatres may be driven by d.c. motors fitted with special speed controls. A shunt field d.c. motor is used, with a speed control in series with the field winding.

(24) A rheostat introduced in series with the field controls the motor speed by controlling the field current. As the rheostat control is adjusted to change the amount of resistance in series with the field, the current flowing through the field changes, hence the motor speed is altered.

(25) It is important to note that *increasing* the current through the field *decreases* the speed of the motor. The reason is as follows: When the armature of a motor revolves, the magnetic force of the field coils, which causes the armature to revolve, also acts to generate a voltage in the armature by induction. This induced voltage is opposite in direction to the driving voltage admitted by the brushes and the commutator, and is called a counter-voltage or counter-e.m.f. The counter-e.m.f. has a slowing-down effect. Under conditions of normal operation an increase in field current is more effective in generating counter-e.m.f. than in increasing speed of rotation, consequently increasing the field current by means of the field rheostat actually has the effect of slowing the motor, whereas decreasing the field current drastically cuts the counter-e.m.f. in the armature, thus causing the motor to speed up.

(26) Automatic speed control for d.c. projector motors may be effected by a centrifugal electric contact, which closes when the motor runs too fast, and in so doing short-circuits the field resistance. The field then receives more current, the motor slows down and the centrifugal contact reopens. The field current is thereby reduced, the motor speeds up until the contact closes again and the cycle of events repeats itself. The motor can never run appreciably faster or slower than the critical speed for which the centrifugal contact is set.

ROTARY CONVERTERS

(27) Theatres which cannot obtain an a.c. supply by reason of their location, nevertheless must have a.c. for operation of the amplifiers of their sound equipment. Although, as stated on Page 109, all amplifiers actually operate by means of d.c., they require d.c. up to several hundred volts for their tubes, and cannot use line d.c. because its voltage is not high enough—it also is not sufficiently steady and might make the sound noisy. Amplifiers are equipped to operate from an a.c. power line accordingly, as already explained. Where a.c. cannot be obtained from an external source it is generated in the projection room. Sometimes the a.c. so generated is also used to drive synchronous type projector motors.

(28) Production of a.c. in the projection room may be merely the reverse of producing d.c. for arc operation as already described. That is, instead of using an a.c. motor to drive a d.c. generator, the process may involve a d.c. motor driving an a.c. generator. However, a device known as a rotary converter is also used. The rotary generator is a device which combines the functions of motor and generator in one set of windings.

(29) As stated in connection with Fig. 62, it is really a.c. that flows in the armature coils of a d.c. generator—the commutator rectifies that current before it reaches the external lines. Conversely, when d.c. is applied to a d.c. motor, the commutator acts to convert it to a.c. within the armature. Consequently, if a commutator be mounted at one end of the armature shaft and slip rings at the other end, a.c. can be drawn from the armature coils of a d.c. motor. This is the essential principle of the rotary converter. It is a device favored because of its compactness and low cost in comparison with a separate a.c. generator driven by a d.c. motor.

(30) Constructional details and internal circuit arrangements of motors, generators and rotary converters used in the projection room vary enormously. The projectionist should obtain the constructional and circuit details of equipments he may have to deal with from the

manufacturer; and study them thoroughly with the help of the basic principles outlined in this chapter.

BALLAST RESISTANCE AND GENERATORS

(31) The term "ballast resistance" as used here refers to rheostats that form a part of motor-generator sets, being used to absorb the difference between the generator and arc voltage. Their purpose will be fully explained in the following pages.

(32) With the shunt type generator there is a very definite relationship between the arc length and current flow on the one hand, and rheostat ballast resistance capacity and arc voltage on the other. The correct voltage across a low intensity (reflector type) arc is between 51 and 57 volts. Across the standard (old style) d. c. arc it varies between 51 and 70. Across the straight high intensity arc it is from 54 to 72 volts.

(33) If the generator operates at 80 volts, supplying a 55 volt arc, it follows ballast resistance exists to absorb or "break down" (80-55) 25 volts, dissipating that amount of power in the form of heat that is absorbed by the surrounding atmosphere. It must be able to do this without over-heating the grids or wire coils. (34) In other words the ballast resistance must have sufficient capacity to do its job without being overloaded; and the greater the amount of voltage it must absorb the greater must be its capacity, remembering always that voltage drop represents wattage (I^2R) and wattage represents power that must be paid for.

One type of error consists in using too much resistance for a given amount of work. Instances have been found where a projectionist was attempting to operate a high intensity arc off an 80-volt generator, using a ballast resistance designed to take care of a 25-volt drop. In such a case, if a 65-volt arc is maintained (the lowest voltage practicable with a high intensity arc), there is a 25-volt resistance and only a 15-volt drop, the result being that the generator cannot force through sufficient current. The remedy is either a higher generator voltage or a ballast resistance suited to the work.

The foregoing is designed to emphasize the importance of maintaining proper relationship between generator voltage and the ballast resistance.

PARALLEL GENERATOR EQUALIZERS

(35) Between two parallel compound-wound generators it is necessary to have a special connection called an equalizer. The reason for this is easily understood. To secure constant potential performance compounding is necessary, which varies in different designs and sizes of generators. In fact it may vary somewhat between two generators of identical design. Even changes which involve alteration in operating voltage and (or) brush position may cause variations.

Presuming two generators to be set for parallel operation their compounding will be balanced by means of a proper equalizer (36) consisting of a connection of a heavy copper bar known as a bus bar between their series coils. This prevents the current in the series fields from differing to any extent, regardless of how much the variation may be in their armature currents.

(37) If, however, one of the generators is started and warmed up to normal operating temperature and the second generator, while still cold, is cut immediately into the circuit with its voltage adjusted to match that of the first machine, what happens?

As the second generator warms up its voltage will drop, compelling the first generator to assume a portion of its load. The field regulation of the second generator must then be adjusted by hand to make up the difference whereupon the load thereafter will be automatically equalized between the two.

Usually two generators will parallel very nicely if connected through a properly designed equalizer, though they may require an adjustment of the field regulators each time at starting to equalize the load.

(38) In motor generator sets not having both motor and generator mounted on one solid base, it is very important that the alignment of the motor and generator

shafts be most thoroughly tested. Unless these shafts are in perfect alignment there will be vibration and perhaps noise.

The test should be made before the flanges are bolted together. (39) This may be done by laying a steel straight-edge across face of flanges; if latter are not machined flat, then a longer steel straightedge, such as a carpenter's steel square, may be laid upon the coupling and aligned with one shaft by caliper measurement and if the alignment is correct the measurement from the other shaft to the opposite end of the straightedge will be the same. This must be done both on top and on the side. Be sure to have the straightedge in perfect alignment with the shaft lengthwise when making the test.

Another though less accurate test is to bolt the flanges tightly together. Then unbolt them and if the flanges surfaces remain in contact all the way around the alignment is correct.

Careful Attention Essential

(40) A motor generator must have careful, intelligent attention in order to work with reasonable efficiency. Many motor generator sets that should work at sixty-five to seventy per cent in efficiency are, because of careless or unintelligent care, working at fifty or fifty-five. Many drop even below that.

(41) To work at maximum efficiency a motor or generator or a motor generator set must (a) be kept clean throughout. (b) It must have the exact size and kind of brushes indicated for the service. (c) Its brushes must make good electrical contact with the commutator over their entire contact surfaces. (d) Brushes must contact the commutator with between 1.25 and 1.50 pounds of pressure per square inch of contact surface. Too little pressure gives poor contact; too much pressure induces sparking and tends to wear grooves in the commutator surface. (e) The brushes must fit in their holders as snugly as possible without binding or sticking. A brush that is loose in its holder will "chatter" and move about,

making poor electrical contact; one that is too tight may stick in its holder and set up very bad sparking. (f) The commutator surface must be kept clean. It should present a smooth, glazed surface, brown in appearance. (g) The mica insulation between the commutator bars must be kept undercut (its surface below the surface of the commutator) from 1/32nd to 3/64th of an inch. The mica must never be allowed to be even with or project above the surface of the commutator. (h) The commutator bar connections (soldered) must be perfect. (i) There must be no sparking, or at best a negligible amount. (j) The commutator bars must not be permitted to wear down unevenly, or to become so thin that they are unable to carry the current without heating. (k) All bearings must be lubricated with oil or grease of the grade recommended by the manufacturer. (m) All wires, switches, etc., must be large enough to carry the load without undue resistance. (n) Allow a slight end-play of the armature in sleeve-bearing horizontal type generators as this aids to prevent commutator grooving.

Effect of Ballast Resistance

(42) One very important item in operating efficiency is that there shall be but the minimum possible ballast resistance interposed in the line, since all resistance above what is strictly necessary to steady the arc is wasted. Unfortunately, in the types of arcs in use at present the stability of the light source depends upon a certain amount of resistance in series with it. This is termed "ballast resistance." If it is too little the arc will be very unsteady and give poor screen illumination.

(43) Experience shows that the steadiness of a projection arc is assured only when there is sufficient ballast resistance to avoid the excessive variation in current flow that comes from irregularities in the arc feed and the consequent arc length and the variations in carbon resistance. (44) The voltage of the generator of a motor generator set above that of the arc is usually not less than 15 volts and often as much as 30.

(45) The skilled projectionist who keeps his arc feed mechanism working perfectly will secure satisfactory results with less ballast resistance.

OIL AND DUST

Keep the motor-generator set scrupulously clean. (46) Oil acts as an insulator, but it will soften the armature insulation, collect dust, grit and metallic particles, and these, if permitted to remain, may in time produce a short circuit with serious damage to the equipment.

Do not permit dust to accumulate around the armature and pole pieces. (47) It is especially important that all dust be blown out from between the pole pieces and armature once each week in all-day houses, and once every two weeks in two-a-day theatres, because the magnetism of the pole pieces gradually collects bits of metal dust from the air and thus impairs the efficiency of operation. Managers should provide a hand bellows of ample size for this purpose.

WORN BEARINGS

(48) Many motors and generators have but little clearance between armature and pole pieces. Naturally any wear in the bearings will reduce the clearance at the bottom and increase it at the top, the shorter gap below becoming a danger point. Projectionists should therefore check up on bearing wear at frequent periods—at least every thirty days. This does not mean that a properly lubricated bearing will wear appreciably in thirty days; it is simply a precaution. If the bearing should fail because of lack of oil distribution trouble may come very quickly.

(49) Ball bearings usually proclaim that they are worn by becoming exceedingly noisy. Sleeve bearings give no warning except through heat.

There is no one best way to check up on bearing wear. A good mechanic will do it almost intuitively. A strip of hard cardboard, about an inch wide and a foot long may be slipped between a pole and the armature. Then, grasping both ends, it can be worked gradually around until it has passed between all poles and the armature surface, thus making sure that no friction exists between the two elements. Because of the dirt that settles on the pole face it is sometimes impossible to see through the air gap; also the gap below the armature may seem smaller than the gap above because more dirt is gathered on the faces of the lower poles. The cardboard removes some of the accumulated dust.

(50) A set of gauges or "feelers" may be purchased from automobile supply dealers. This is a series of thin steel strips varying usually from .002-in. to .010 or .015-in. in thickness. They are held together in a frame like the blades of a jack-knife and can be laid together in any desired combination so that by building up to any desired thickness and inserting it into the gap, the width of the gap can be tested accurately.

(51) An equally efficient check is to pry with a bar inserted under some exposed part of the armature shaft. Pressure will make the armature rise in the bearing if the bearing is worn. The "looseness" of the bearing indicates the wear.

(52) It is impossible to say how often the oil should be replaced, as its useful life depends upon many factors. such as the hours of operation per day, the bearing and room temperature, the quality of the oil used, peripheral speed, air condition and so on. Motors are known to run for long periods without a change of oil. On the other hand dust may settle on a neglected bearing, drawing out the oil by capillary action in a few weeks' time. It is best to look at the oil whenever the machine is inspected. If it is clean and at the proper level it needs no attention.

(53) A proper oil is a highly important item. The journal and bearing will wear down rapidly with poor quality lubrication or one that is unsuited to the work.

To save half a dollar on a gallon of oil that brings about ten dollars worth of unnecessary damage to machinery is exceedingly false economy.

It is best to ask the manufacturer to recommend a lubricant and to follow his recommendation even though he may name an oil he himself supplies. His reputation requires that his machine perform well, and he is extremely unlikely to suggest anything but what is proper.

BALL BEARING LUBRICATION

(54) Be exceptionally careful about the lubricant for ball bearings. It must be wholly free from acid because acid will roughen quickly the polished surface of the balls and their races. Grease that contains animal fat is acidic and should not be used. Here, too, the manufacturer's advice should be followed implicitly.

INSTALLATION SUGGESTIONS

(55) Immediately upon receipt of a new motor-generator set examine its name plate, making sure that the voltage, phase and frequency of the motor and amperage capacity of the generator are what are required for your particular purposes.

Sometimes, after all the work of installation has been completed one of those factors has been found to be wrong, whereupon the whole set had to be removed and another installed. (56) Small two or three-phase motors, say up to and including 5 H.P. capacity, usually may be connected with the line merely by closing a switch. For larger motors a "compensator" or variable resistance starter is required.

(57) All wires must be large enough to carry the current without developing unnecessary resistance (voltage drop), which of course means waste. (58) It is a mistake to consider the installation satisfactory if the wires merely carry the maximum current permitted by the Underwriters. Underwriters' wire capacity restrictions indicate safety for wires and insulation but offer no guarantee of real economy in operation. As a matter of fact, any wire working at maximum Underwriters' capacity will offer enough resistance to show considerable waste of power wherever current costs are high. It is much more economical and more efficient to install wires larger than the Underwriters call for. The saving on current consumption will be much greater than the initial cost of the larger wires.

(59) In installing the main projection room circuit and the circuits feeding the projectors, spots, effect projectors and stereopticons, be sure to make ample allowance for possible future increases in current consumption. You may think this an unnecessary suggestion but the cost is little and the precaution is wise. It is both expensive and troublesome to be forced later to pull out all the wires and install larger ones, or to run an auxiliary circuit. In any event install conduit large enough to accommodate larger wires, should they become necessary.

(60) The voltage drop of any wire circuit may be ascertained by multiplying the one-way length of the circuit by 21; multiply the product by the amperes and divide the result by the circular mil area of the wire. This will give you the voltage drop.

(61) Before purchasing a motor-generator set for the projector arc supply, make sure that the generator performance curve is flat (constant voltage over the amperage range of the generator) at the level at which the set is to operate.

INSTALLATION

(62) It is extremely unwise to locate a motor-generator set in a basement or any place far removed from the projection room. A good set is quiet enough to be installed in a room immediately adjacent to the projection room, provided it is placed on a support or foundation sufficiently solid to avoid vibration. Furthermore the set should sit immediately on either rubber, cork or springs, which will absorb any slight vibration the machine may create.

(63) Located thus the motor-generator set will be under the constant observation and care of the projectionist which it cannot have when removed far from the projection room. Moreover, basements are often damp and sometimes flooded—both of which damage the equipment.

SPACING

(64) Be sure to leave clear space on every side of the

set. Men must have room to work around a set if it is to be well taken care of. Install a drop light (preferably a reel light) on a long cord so that the projectionist may be able to illuminate any part of the machine without difficulty.

A thick layer of cork or rubber absorbs vibration for a time, but with the passage of time these substances lost a part if not all of their resiliency. (65) Were we considering the installation of a motor-generator set in a theatre of our own, we would set it on coil springs not less than six inches long, and of such capacity that four of them, one under each corner, would carry the weight with no more than one inch depression. Coil spring supports are not expensive. Any responsible spring manufacturer will supply them. Order four springs that will carry the weight of the set and he will guarantee sufficient resiliency to absorb all vibration.

It is necessary to make a strong concrete base of proper depth and size and sufficiently massive, with a half-inch bolt embedded head down near each corner and protruding about one and one-half inches above the surface. The springs themselves should consist of a spiral of from four to five inches diameter at one end, tapering to about two and one-half inches at the other, the extreme small diameter of the steel being turned in to the axis of the spring and curled to take a half-inch bolt readily.

The smaller end of the spring is then bolted to the bottom of a wooden frame on which the motor-generator set is to rest, or directly to the bottom of the cast iron or steel base of the set. The larger ends of the springs are attached to the ends of the imbedded bolts. The taper of these springs gives the assembly more stability than would be had were they cylindrical, without at all decreasing their action. With such an arrangement (which sounds complicated but is very simple and low in price) we will guarantee despite the fears of many exhibitors that neither vibration or sound will be communicated to the building.

If the manufacturer of the set, or the contractor who is to install it, is a responsible factor, and desires to support the set by some other method, and is will to guarantee, in writing, against noise or vibration, such guarantee should be accepted.

BRUSHES

(66) Points of importance with relation to brushes are: (a) they must fit their holders snugly, but not so tight they will stick in their holders. (b) they must relate to the machine in size and be able to carry its maximum current without heating; (c) when new brushes are installed they must be fitted accurately to the commutator curvature. (67) This last may be done by laying No. ½ sandpaper (never emery cloth or emery paper) on the commutator, the ends of the brushes resting on the sand side at normal brush pressure. Draw the paper forward in the direction of the commutator rotation, and repeat the operation until the brush ends fit the curvature perfectly.

If the brushes fit their holder snugly the job may be done more easily and quickly by drawing the paper back and forth until the brush ends are worn almost to the proper curvature. At the finish it is best to draw the paper a few times in the direction of the commutator rotation only. It is a tedious job, but only needs to be done at long intervals.

Do not experiment with brushes. Use only those recommended by the manufacturer of the set.

THE COMMUTATOR

The careful projectionist will pay close attention to the generator commutator. He will study its requirements and if something seems wrong will attend to it immediately. Sparking cannot always be eliminated entirely, especially if the machine is working close to capacity, but it should be reduced as far as possible. The instructions that follow are of great help.

(68) When there is little or no sparking and the surface is smooth, glazed and of a dark brown color it is

the best evidence that the commutator is in the finest possible condition. If the condition is good there will probably be a slight squeak from the brushes when the armature is rotated slowly, though its absence does not necessarily indicate that anything is wrong.

Yoke Mark

(69) On all modern types of motor-generator sets the correct setting of the brush yoke is indicated by a mark on the yoke and another on the frame. These should be exactly opposite each other. This setting does not contemplate a continuous overload or underload. If that is the case the brushes may need advancing or retarding.

To Test Brush Pressure

(70) An experienced man can test brush pressure with sufficient accuracy by raising the brush finger or spring. If the commutator has little or no sparking and the proper glaze, it is best not to touch it at all. For the brushes usually found on a commutator used for dynamos of this type a pressure of from one and one-quarter to one and one-half pounds per square inch of brush surface is approximately correct. A small spring balance will measure such a pull quite accurately. This may be hooked to the brush holder finger or spring and the latter raised just out of contact.

(71) If at this point—when the finger is worked up and down by raising and lowering the scale—it is found that there is a wide difference in the scale of reading, it shows that the brush finger is too tight and the chances are that a good cleaning is in order. The purchase price of the scale is fully justified by the discovery of an undesirable condition even in a single brush holder.

If the brush is, for example one and one-half inch wide by three-eighths of an inch thick its contact area is roughly nine-sixteenths of a square inch, so that the balance reading should be fourteen ounces.

The width times thickness will serve for calculating contact surface. The curvature of the contact face makes some slight difference, but not enough to affect results appreciably.

(72) A fresh, new rubber band with a piece of string at each end, previously calibrated as to stretch by lifting, say a pound, gives excellent results. The elongation of the rubber when raising the brush holder finger can readily be measured and is almost exactly proportional to the weight raised. In the example already cited we should expect fourteen ounces to stretch the rubber seven-eighths of an inch if the pound weight elongated it one inch. Or exact results may be had by first calculating the exact pressure the brush should have and then raising an equal weight (measured on a reliable scale) with the rubber, noting the exact amount of stretch.

CARE OF COMMUTATOR

Much depends upon the care the commutator receives.

(73) Unless the commutator is in good condition you will have sparking, which operates immediately to roughen and "pit" the commutator surface, thus making the condition progressively worse.

CLEANLINESS

The commutator must be kept clean and smooth.

(74) Aside from a daily endwise brushing to remove dust and other deposits from the undercut slot between the communtator bars, there should be little need for cleaning unless too much lubrication, or lubrication of the wrong kind has been applied, or the brushes contain too much paraffin.

(75) Once every ten hours of operation the commutator should be brushed *lengthwise,* using a brush with bristles as stiff as may be without danger of injuring the surface. This is to remove from the undercut grooves between commutator bars any dust or foreign substance that may have lodged there. Much of the dust is carbon scraped from the brushes and copper worn from the copper bars. This worn copper is, of course, a conductor.

SANDPAPERING

(76) In the event it becomes necessary for any reason, to clean the commutator surface right down to the copper, use No. 00 sandpaper. Do not use anything coarser than No. 00 and under no circumstances use emery paper or emery cloth. Remove all brushes and, having started the motor (we are still considering motor-generators), hold the sandpaper against the commutator, without exerting too much pressure, until the copper shows clean and bright all over the surface.

(77) Stop the motor and give the commutator a vigorous brushing endwise. Next whittle a hardwood stick until its point will just fit into the undercut between commutator bars. Draw this through each one of the undercut slots to dislodge any copper bits that may have been drawn either across from one bar to another or down into the groove. Then brush endwise again vigorously.

(78) There are "commutator stones" on the market, which are rectangular bricks of fineness or coarseness to suit any "dressing" job.

The stone is held against the rotating commutator, and its surface wears down readily to fit the commutator curvature, in the meantime cutting freely. Unless the brushes are raised, they too will partake in this rapid wear-away-spree. In fact one way of fitting the brush ends to the commutator curvature is to let them rest in their natural position on the commutator and operate with a rather fine grade of commutator stone. The fit thus secured is perfect.

(79) After the stoning is finished, brush vigorously endwise to remove all grit and bits of copper from between the bars. Next, hold against the rotating commutator the lubricating pad which we shall presently tell you how to make. Then adjust the brushes and the commutator "dressing" is done.

COMMUTATOR LUBRICATING PAD

(80) To make this pad proceed as follows: From a

medium-weight canvas cut a piece about six inches square and fold it so that it forms a pad 6 inches long by two inches wide. Dampen and press down, so it will stay folded.

Open the pad and along the center section of the inside of the pad, apply a light coat of ordinary vaseline. Refold the pad and lay it aside for a day in a warm place, to give the vaseline time to soak through the fabric. After this the pad should be kept in a closed box where it will be free from dust and dirt. The pad may be recoated with vaseline from time to time whenever it requires it.

By holding it against the commutator for a few seconds the commutator will receive all the lubrication it requires. If soft brushes are used apply no lubrication, as they contain sufficient paraffin for the purpose.

Commutator Conditions

Reduce sparking to an absolute minimum. (81) There should be little or none unless the machine is overloaded. If there is sparking and the machine is not overloaded, proceed at once to ascertain its cause.

(82) The easily discoverable causes are as follows: brushes improperly set; wrong brush pressure; poor brush contact; high commutator bar; improper brushes purchased for replacement; commutator out of round; commutator dirty; high mica.

Make sure that combined oil and carbon dust has not formed a short between the bars or formed a spot of semi-insulation on the commutator face. Be sure the commutator has no high bars and that it is perfectly round—either of these faults can be tested for easily.

(83) High bars may be detected ordinarily by a slight clicking sound when the machine is run at moderate speed, which can be accomplished without load by manipulation of the switch. There can be also a low bar or bars, in which case the brush would ride inward slightly as the armature is rotated slowly by hand. If the commutator is out of round, that fact may be made evident by rotating the armature slowly by hand,

watching the brushes closely for an up and down movement in their holders.

(84) Often a very slight motion of the brushes up and down in the holder means nothing. It is sometimes impossible to get them to ride without some such slight motion. Commutators are turned originally on lathe centers, but in the generator the shaft revolves on bearings. The shaft center may be out of true with the journal a fraction of a thousandth of an inch, or the shaft may be slightly sprung. Perfection here is seldom reached. It will be unwise for anyone except the most experienced machinist to attempt to remedy such faults. In such cases the business of the projectionist is only to detect and report them.

(85) Test for "out-of-round" by resting some blunt-pointed tool on a solid support, its face just in contact with the commutator, and rotate the armature slowly by hand, noting whether or not the contact is constant through one complete rotation.

Points that Need Watching

(86) Be sure no bit of copper has dragged across from one commutator bar to another. In that event a ring of light will appear, seemingly entirely around the commutator. Remove the trouble-making copper.

Make sure that the brushes all fit properly in their holders and that the holders are free from all accumulations of dust and dirt.

Be sure, if the set is one in which the armature lies horizontally and is not ball bearing type, that the armature has endwise movement (called "float") of at least three-sixteenths of an inch. This is quite important since it helps to prevent the brushes from cutting grooves in the copper. To have "float" it is essential that the armature rest almost in exact horizontal position. See that this is the condition when the equipment is installed.

The insulation between the commutator bars must be kept undercut to the proper depth.

The brush yoke must be set at exactly the position indicated by the mark, which should be present on both the generator frame and yoke. Any error in the yoke set in a normally loaded machine will cause brush sparking and a decrease in efficiency.

Be sure that there is some protection over the commutator to keep things from dropping upon it. This does not mean simply a screen such as the manufacturer furnishes as a guard against accidents. Cases have occured where the commutator was ruined and the winding burned out as a result of pieces of plaster dropping from a wall overhanging the machine. There should be a solid baffle of metal, or its equivalent, not too far above the commutator surface.

Sticking Brushes

(87) Brushes often stick in their holder when they fit too snugly or bits of dirt and grease work their way in between the brush and the holder or the brush itself is not true on its surfaces. The last is an unlikely fault, but is sometimes found. To correct it tack No. 0 sandpaper on a perfectly flat board and rub the brush on it gently until its surfaces are true. Kerosene is excellent to remove the sticky grease and dirt mixture that sometimes accumulates on the brush rigging. Carbon tetrachloride is still better.

Commutator Too Thin

(88) Commutators gradually wear down through friction. After being trued up repeatedly in a lathe the bars may become too thin to serve adequately. As the bars get thinner from wear the ends no longer have a firm mechanical support, since the clamp or lock is near the center of the length of the bar. This condition will cause chattering, sparking and heating, because the individual bars are disturbed when the brushes pass over them. Install new bars.

Uneven Wear

(89) It is possible for some commutator bars to be

slightly softer than others, and thus tend to wear down faster, causing sparking and a roughened surface. The remedy is resurfacing in a lathe.

HOT BRUSHES

(90) Too much heat in a brush indicates a misplaced brush or a poor contact. The brush is heated either from poor contact within itself, or because the other brushes in the same line have poor contact and carry practically nothing, throwing the whole burden of carrying the current upon the hot brush. Examine the brush contacts and the brush pigtails. Remember that nearly all brush deficiencies produce heat.

LOW BEARINGS

(91) This has been mentioned before, but is again referred to because worn bearings will, at least with some types of machines, throw the magnetic field sufficiently out of balance to cause sparking at the brushes. Here the air gap at the top of the armature will exceed that at its bottom. The gaps should be made equal. New bearings are indicated.

"SHORTED" COIL

(92) A short-circuited armature coil puts the generator out of business promptly. The "shorted" coil will heat up quickly. The short may either be in the coil itself, or at a connection between two commutator bars.

BENT ARMATURE SHAFT

(93) A bent armature shaft is evidenced by increased vibration. It is unwise to attempt to have it straightened. A new shaft is the only reliable remedy.

OVERLOAD

(94) Overload causes the whole armature to develop excessive temperature; it also causes brush sparking that cannot be stopped, though it can be reduced by shifting the brush yoke slightly from its normal position.

(95) A well designed, well constructed motor-generator set should withstand an overload beyond its nameplate rating, which for projection work already presupposes a temporary overload. It should be able to withstand indefinitely a ten percent continuous overload beyond nameplate rating. Imposing a continuous overload in any amount, however, is very bad practice, as it makes for inefficient operation and rapid deterioration.

Weak Field

(96) If your generator does not pick up its load readily or will not retain its normal voltage while in operation, it is evidence that its field is weak. This fault in a motor will decrease its starting power but increase its speed and current consumption. (97) A weak field may have its seat either in a loose connection somewhere in the field circuit, or it may be caused by a short-circuiting of the current through field windings induced by weakened insulation caused by abnormal heat or otherwise; or it may be caused by a metallic short in the field coil. Test across each coil with a voltmeter. The defective coil is the one showing the least drop. If all readings are identical, the trouble, you may be sure, is due to a loose joint in the magnetic circuit.

Undue Vibration

(98) Too much vibration in a generator may cause brush sparking. Immediately after installation of a new motor or generator, place your hand on its frame. If serious vibration is detected, refuse the machine. Modern motors and generators can be so balanced that there need be no discernible vibration.

Ring of Fire

(99) Should a ring of fire appear on the commutator it will be due to one of two things: it is either a current-carrying material that connects two or more commutator bars or it is an open circuit in the armature. If it is the first, the "ring" will be bright and pronounced. If it is

impractical to stop the machine at the time, hold a piece of 00 sandpaper against the fire ring lightly. This should stop it unless the connection is in an undercut below the commutator surface. Don't use the sandpaper if it is practical to stop the machine and hunt up the defect.

(100) An open circuit in the armature will eat into the mica between the two bars connecting the faulty coil, and may invade the bars themselves. The machine should be stopped at once. It may be a broken coil wire or the commutator bars may have loosened and broken off one or more of the leads. The machine will be out of commission until the trouble is remedied, the length of time required for repairs depending upon how much damage has been done before the trouble is discovered.

OVERHEATING

(101) Through comtinued overload, abuse or just plain carelessness, it may happen that temperature will develop in the armature and melt the solder connections between the commutator bars and coils. The liquid solder will be thrown out, though there may be no complete opening of the circuits. Stop the machine immediately or the commutator will be ruined.

HOT BEARINGS

(102) Should a bearing run hot, immediately drain and refill with fresh oil. See to it that the oil ring is not "stuck." If the heating is sudden and violent, shut the machine down and make a careful examination of the bearing. We are assuming, of course that the oil has not been permitted through carelessness to drop too low. If it has, drain the bearing, flush it out with thin oil to wash out a possible metallic scale induced by heat and refill with fresh oil.

(103) Never directly apply water to cool down a hot bearing unless you want additional trouble. (104) Sometimes when a moderate bearing heat develops, a change to a different oil, heavier or lighter, will correct the trouble. However the better plan is to keep the machine running, flooding it with a not-too-heavy oil,

meanwhile putting cold applications on the outside of the oil well. Cloths wrung out of cold water should soon reduce the temperature so that the machine can be shut down without danger of the bearing and journal "freezing" together.

(105) When a bronze bearing in a new machine runs hot it is in danger of "freezing" to the shaft if the machine is immediately shut down and this means the bearing must be turned or chopped off the shaft and a new one installed.

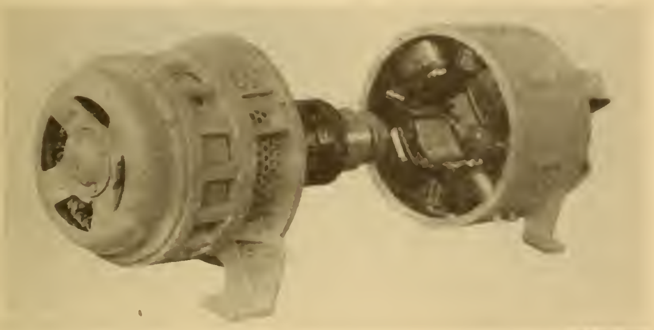

HERTNER

FIG. 74A.—Theatre arc supply motor-generator partly disassembled, showing generator field coils at right of illustration.

PERMISSIBLE TEMPERATURES

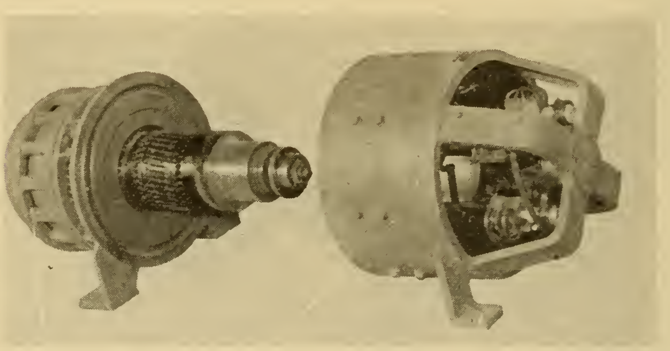
(106) The fact that parts of a motor or generator feel uncomfortably hot to the touch does not necessarily indicate trouble. Every room in which motors and generators are located should be equipped with a reliable thermometer having, by preference, both Centigrade and Fahrenheit scales, the latter reading not less than 200 degrees.

(107) The standard regulations of the American Institute of Electrical Engineers permit a maximum temperature of 90 degrees Centigrade, which equals 194 degrees Fahrenheit, for motors and generators and any part thereof. Since the human body, ordinarily, has a temperature of about 98 degrees, a motor or generator part may feel very hot to the touch, though still at safe

operating temperature. This feeling of danger is particularly true when on a hot day the perspiring hand is laid against any metal part of the set.

MEASURING MOTOR TEMPERATURE

(108) Bed the thermometer ball in stiff putty, then bed the putty on the part to be measured, leaving it in contact for an ample time so the putty will heat fully through. Be sure to use stiff putty, otherwise it will get very soft and run under the action of the heat.



HERTNER

FIG. 74B.—Same motor-generator as in FIG. 74A, showing generator armature and commutator at left, brushes and brushholders at right.

To reduce Centigrade to Fahrenheit (C. to Fahr.), multiply degrees Centigrade by 1.8 and add 32. For example, 40 degrees Centigrade will be 40 x 1.8 plus 32 which equals 104 degrees Fahrenheit.

BATTERIES

Practical Questions

(For answer to each question see statement of corresponding number in Chapter VIII)

ELECTRO-CHEMICAL FUNDAMENTALS, PAGE 163

1. Of what does a "C" battery consist?
2. What is a "B" battery?
3. Under what circumstances, and how, can B batteries be helpful in the projection room?
4. What is the difference between a battery and a cell?

THE DRY CELL, PAGE 163

5. What action, in a dry cell, detaches electrons from their atoms?
6. Where are they to be found after they have been so detached?
7. What force causes them to move through an external circuit?

THE STORAGE BATTERY, PAGE 164

8. Under what circumstances, and how, can storage batteries be helpful in the projection room?
9. When a storage battery is in use (discharging) what happens at the negative plate? At the positive plate?
10. Where, in a storage battery, does lead sulphate form?
11. Where does the sulphate in the lead sulphate come from?
12. What is the effect of discharge upon the solution of a storage cell?
13. With what instrument can that effect be measured?
14. Will that instrument indicate the state of charge of the cell? Why?
15. What action in the cell causes a storage battery to lose voltage in the course of discharging?
16. What does re-charging the cell do?

17. Name two causes of deterioration of a storage battery.
18. Why must a storage cell be over-charged occasionally?

CARE OF STORAGE BATTERY, PAGE 166

19. What precaution is necessary in charging a storage battery?
20. What is "gassing"?
21. Name two kinds of injury caused by excessive gassing.
22. Name three necessary precautions in the care of storage batteries.
23. Does the battery acid evaporate? Is it lost in any other way?
24. Why are battery terminals kept greased?
25. What damage is done by unclean battery tops?
26. What kind of water is used to re-fill storage batteries? Why?

CHAPTER VIII

BATTERIES

(1) One of the simplest and most familiar sources of electrical voltages and currents is the common zinc-carbon "dry" cell that is used in flashlights and for theatre intercommunicating phones. A variation is used in a few theatre amplifiers as a source of "C" voltage for amplifying tubes.

(2) In portable, battery-operated radios of certain types a special form of these devices also supplies current and voltage to the "B" circuits of the amplifying tubes, and is known as a "B" battery.

(3) B batteries are useful in some projection room emergencies, because a sufficient number of them can supply "B" current and voltage temporarily for the theatre's amplifiers, or polarizing voltage to the theatre's photoelectric cells. Hence, in sound troubles which involve some fault in the supply circuits just mentioned, a number of B batteries obtained at the nearest radio store may serve to keep the show going until more complete repairs can be completed.

(4) Although B batteries in common use deliver 67½, 90 or 135 volts, no dry cell ever delivers more than a fraction above one volt. The B battery is a battery or group of individual cells built together to form a single unit, with all the cells wired in series so their voltages will add. Flashlight cells, on the other hand, are usually single cells. They are not "batteries"—a battery being a group of cells—but they are called batteries by a common, almost universal error.

THE DRY CELL

(5) The source of the electrons obtained from a dry cell is the zinc metal that forms the container. The in-

terior of the cell is filled with a semi-wet paste that contains, among other things, molecules of ammonium chloride. The chemical action of the paste upon the container is such that some of the zinc atoms are positively ionized, whereupon they dissolve into the paste. The electrons they lost when they became ions remain behind, (6) constituting a charge upon the container.

Just as there is a limit to the amount of sugar that can be dissolved in a cup of coffee, there is a limit to the amount of zinc that can be dissolved in the paste of a dry cell. In the center of the cell, however, there is a carbon rod, which is in intimate contact with the same paste. When the carbon rod is connected with the zinc can by means of an external wire, forming a closed circuit, the process of dissolving zinc becomes continuous, and a steady supply of electrons is released at the zinc or negative terminal of the cell.

This happens because the electrons already accumulated on the zinc are driven, (7) by force of their mutual repulsion (which is voltage) to move through the connecting wire to the carbon rod. There they enter into the solution and break up the ammonium chloride molecule by upsetting its electrical balance. A new molecule is formed, in which the zinc that had been dissolved from the can is included. The paste then becomes able to dissolve more zinc, leaving more electrons behind on the container, and the process can continue as long as the can and the carbon rod are connected by a conductor and the cell is still "alive." But after it has continued for a period of time the battery "dies," partly because the active material of the paste has been exhausted and partly through a variety of chemical changes, the small details of which are not of great interest to projectionists.

THE LEAD STORAGE BATTERY

(8) The lead storage battery (common automobile battery) is useful in some projection room emergencies, since one or several such batteries can be used to keep the show going when certain types of trouble are encountered. Specifically, storage batteries can supply "A"

current for the cathodes or filaments of amplifier or rectifier tubes. They can supply current for the exciter lamps (for the source of the light that is used to excite emission in the photoelectric cell, see Chap. 20). Certain types of theatre loudspeakers incorporate electro-magnets of such characteristics that they also can be supplied with current by means of storage batteries if the regular source of current for them should develop trouble. There are theatres that have complete storage battery installations for emergency lighting, to be used if the regular power supply fails; these installations may or may not be under the care of the projectionist. The common, automobile type battery consists of three cells built together in a single unit and connected in series; each cell delivering 2.4 volts when fully charged and 1.8 volts when its charge is exhausted.

The chemistry involved in the action of storage battries is more complex than that of dry cells, and will be dealt with only in brief outline. The full story of that battery, as well as of the dry-cell, can be found in any modern text-book of chemistry. (9) (A) Sulphate ions in the sulphuric acid which storage cells contain unite with the lead of the negative plate to form molecules of lead sulphate. (B) Each atom of lead that enters into this combination loses two electrons, which move through the external connections the to positive plate. (C) Here their presence breaks up molecules of lead dioxide, each of which consists of one atom of lead and two atoms of oxygen. Through an intermediate chemical formation, that need not be traced in detail, the presence of these electrons results in the formation of lead sulphate on the other plate also, as well as the release of oxygen. (10) (D) The sulphate that goes to make up the lead sulphate formed on both plates (11) comes from the sulphuric acid, which is only another name for hydrogen sulphate. Divorced by its sulphate partner, the hydrogen unites with the oxgen released at the positive plate, forming water. (12) Therefore when the battery has been used for a while its solution contains less sulphuric acid. and more water. (13) This change can be measured with a hydrometer. (14) In consequence that simple instrument tells how far the cell is exhausted, and whether it stands in need of recharging.

(15) (E) The lead cell of storage batteries must be re-charged long before its sulphuric acid is all used up, because the lead sulphate that forms on both plates ultimately becomes thick enough to insulate the solution from the active material, therefore the chemical action slows up and the voltage of the cell declines.

(16) (F) Re-charging of this cell involves the introduction of new electrons from an external source, which by their presence upset the electro-chemical balances created during the state of discharge and restore the original condition. The amount of sulphuric acid in the solution is increased during charge as the sulphate leaves the plates, and the oxygen divorces the hydrogen to return to its original partnership. The hydrometer measures this change and tells when the battery has been completely re-charged.

(17) Storage batteries deteriorate through several causes. In commercial batteries some of the active material drops from the plates during each cycle of charge and discharge, piling up at the bottom of the cell. Thus the plates lose some of their power. Eventually the heap of material at the bottom may grow high enough to short-circuit them. Again, the lead sulphate that forms during discharge is seldom completely disintegrated during charging. A surplus usually remains that must be removed by occasional over-charging. (18) If this is not done the layer continues to accumulate until it has become so thick that no ordinary charging will remove it and the battery must have special treatment or be thrown away. There are other causes of battery deterioration but these two are of prime importance. Others are described below.

CARE OF STORAGE BATTERIES

(19) While it is necessary, as has just been explained, to overcharge a lead battery occasionally, it is much

more important not to overcharge it often or unintentionally.

(20) All charging boils out some of the water of the solution—a process called "gassing." (21) Gassing loosens active material from the plates and causes it to fall to the bottom of the container as sediment, thus shortening the life of the battery. Gassing, and therefore charging, should consequently be limited to just so much as is necessary to prevent accumulation of excess lead sulphate, and no more. Excessive gassing may also cause some of the sediment to boil up from the bottom and deposit on the plates or the porous separators between the plates, thereby forming an internal conducting path that partly short-circuits the cell. (22) Manufacturers' specifications as to charging should be followed carefully and intelligently. Otherwise the cell needs only external cleanliness, and periodic replacement of the water that has evaporated.

(23) The acid does not evaporate but some spray of acid will be blown out of the ventilation openings by gassing during charge. Generally, the amount of acid lost in this way is so small that new acid will never be needed during the life of the battery. Sulphuric acid is not added to batteries. If it is needed the cell is emptied and a new solution of acid and water poured in; which is not, in general, a job for the projectionist, but for a battery expert. (24) The acid lost through gassing, though not enough to make much difference inside the cell, becomes, however, a very serious matter when it collects on the outer surface. It corrodes the terminals and the connecting wires to an extent that may result in imperfect contact and therefore in noisy sound.

Trouble from this source is prevented by keeping the terminals of the battery carefully greased. This is a very important precaution.

(25) Spray of acid collecting upon the top of the battery forms a conducting path of high and often of variable resistance. Noisy sound may be caused by unclean battery tops. Acid spray should be carefully washed off with excess of pure water. Ammonia will

neutralize the acid and a weak solution of it is sometimes used for washing the tops of storage batteries.

(26) The only safe water to use in a storage battery, to make up for evaporation, is distilled water. Hydrant water in some communities will do no harm at all, but in others ordinary harmless drinking water contains metallic impurities that will damage the battery seriously. Distilled water is too cheap to justify taking chances with an expensive battery installation.

LENSES AND MIRRORS

Practical Questions

(For answer to each question see statement of corresponding number in Chapter IX)

1. Why must the projectionists understand certain laws relating to light action?
2. Recite the law dealing with light from open sources.
3. Examining Fig. 75, what effect would you say has distance from an open light source upon a surface to be covered by the light?
4. Does light travel in straight lines?
5. Under what circumstance does a light ray change its course?
6. What effect has distance from an open light source upon brilliancy of illumination?
7. What optical train is particularly difficult?
8. What does the first optical system of a motion picture projector do?
9. What is the second optical system of a projector and what does it do?

DEFINITIONS, PAGE 181

10. What is the Angle of Incidence?
11. What is meant by Angle of Refraction?
12. What is meant by Barrel Distortion?
13. What is a plano-convex and a bi-convex lens?
14. What is meant by Brilliancy?
15. What is meant by Collector Lens?
16. Describe a compound lens.
17. What does the term Conjugate Foci mean?
18. What is meant by Converging Lens?
19. In projection optics what is meant by a Condenser?
20. What is Chromatic Aberration?
21. What is meant by Equivalent Focus?
22. Do the faults in a simple lens alter its focal length?
23. What is meant by Critical Angle?
24. What does the term Focal Length mean?

25. What is meant by Free Diameter with reference to lenses?
26. What is Incidence?
27. By what means are lenses corrected?
28. What is a light ray, or a ray of light?
29. What is a Meniscus Lens?
30. Optically, what does the term Perpendicular mean?
31. What is meant by the Plane of a lens?
32. Describe a plano convex lens.
33. What is the Principal Axis of a lens?
34. What is the Projection Angle?
35. What is Refraction and what causes it?
36. What is meant by a Simple Lens?
37. What is Spherical Aberration?
38. What is meant by Working Distance of a projection lens?
39. What difference is there between Working Distance and Back Focus?

LENS ACTION, PAGE 185

40. Upon what is lens action wholly based?
41. Does each pin-point of the surface of a lens refract light differently?
42. Does a light ray change its course while passing through the body of a lens?
43. Upon what three things is lens action upon light dependent?
44. If a ray of light meets both surfaces of a lens exactly at right angles what will happen?
45. If a light ray meets a lens surface at an angle what happens?
46. Explain the various points in connection with Fig. 33.

IMAGE FORMATION, PAGE 188

47. Examining Fig. 79, explain how the image of object X is formed.
48. Are uncorrected lenses faulty and how may they be corrected?

FOCAL LENGTH, PAGE 189

49. What is meant by the focal length of a simple lens?
50. By what elements of a lens is focal length chiefly affected?

LENS CURVATURE, PAGE 190

51. Of what surface are the surfaces of lenses (except parabolic) used in projection duplicates?
52. What would be the optical result of placing two plano-convex lenses with their flat surfaces in contact?
53. What is the effect of spherical aberration?
54. In what way may spherical aberration have considerable value?

LENSES CANNOT FOCUS OBJECTS TO A POINT, PAGE 191

55. Explain why it is impossible for any lens to focus any object to a point.
56. In just what manner is an image formed by a lens?

THE PROJECTION LENS, PAGE 191

57. What kind or variety of lens is the projection lens?
58. Does balsam sometimes deteriorate or "melt"? What must be done if it does?
59. What is the advantage and disadvantage of cementing the rear lenses?
60. If one element of a compound lens is injured or broken, must the whole lens be sent to the manufacturer for repair?
61. Why must the broken part of a lens be included in the shipment?
62. Have odd lenses or parts of compound lenses any value?

ORDERING LENSES, PAGE 192

63. When ordering lenses, what data must be supplied to insure proper selection?

RANGE OF PROJECTION LENS FOCAL LENGTHS, PAGE 193

64. What focal length projection lenses are carried regularly in stock by manufacturers and some dealers?

65. What is the safest method of matching a lens?
66. What information should be transmitted to the manufacturer in ordering a lens to match another?
67. Describe the marking used by one lens manufacturer.
68. How are matched lenses marked?

LIGHT LOSS THROUGH REFLECTION, PAGE 194

69. What, according to optical engineers, is the reflection light loss per surface?
70. To what else is light loss due?
71. Is light loss the only evil effect of dirty lenses?

CLEANING LENSES, PAGE 195

72. Does a very small amount of oil injure results?
73. Do even the faintest finger marks do harm?
74. How may faint finger marks be made visible?
75. What is best for cleaning lenses?
76. How often should lenses be examined?
77. When should mirrors be cleaned?
78. Should projection lenses be disassembled occasionally, the interior surfaces of the lens elements cleaned and the lens coating examined?
79. Why is the projection lens barrel painted black inside?
80. What should be done if the black interior coating wears off?
81. What should all projector lenses makers do?
82. What marks should be affixed to projection lens elements by projectionists?
83. What should projectionists be very cautious about in disassembling and reassembling projection lenses?
84. Just how tightly should the mount be screwed up when assembling lenses?

LOSS THROUGH ABSORPTION, PAGE 196

85. How much light is absorbed in passing through crown or flint glass?
86. What is the loss in poorer grades of glass?

TESTING FOR BARREL OR PIN-CUSHION DISTORTION, PAGE 197

87. What is the effect of barrel distortion; of pin-cushion distortion?
88. Should projectionists test their lenses for barrel and pin-cushion distortion?
89. How test for barrel or pin-cushion distortion?

TESTING FOR FLATNESS OF FIELD, PAGE 197

90. Describe a simple process of testing a projection lens for flatness of field.

THE WHY AND WHEREFORE OF FOCUSING, PAGE 198

91. Does a cone of light go forward from every pin-point of the film photograph?
92. What is the function of the projection lens with relation to the cones of light from each pin-point of the film photograph?
93. If distance from the film photograph to the projection lens is altered in the least degree, what happens?
94. Examine Fig. 83 and explain the action it illustrates.

DEPTH OF FOCUS, PAGE 198

95. Is depth of focus definitely a physical condition?
96. To what is depth of focus proportional?
97. Do all lenses of equal diameter, equal correction and equal focus have also equal depth of focus?

ALTERING FOCAL LENGTH, PAGE 199

98. Is it possible to alter the E.F. of a projection lens by lengthening or shortening the distance between front and back factors without injury to the lens?

PICTURE DIMENSIONS AND E. F. OF PROJECTION LENS, PAGE 199

99. Can any projection lens be made to project a picture at any distance?

100. Will any projection lens project the same size screen image at different distances?
101. What effect has longer or shorter E.F. upon working distance?

MEASURING FOCAL LENGTH OF SIMPLE LENSES, PAGE 199

102. Is it possible for projectionists to measure the focal length of simple lenses—a plano-convex lens for example—accurately?
103. Is it possible to measure simple lenses with sufficient accuracy to serve all practical purposes for projection work?
104. Describe the process of measuring the focal length of a simple lens.
105. How may the focal length of bi-convex lenses be measured?
106. What rules govern the measuring of the focal length of simple lenses?
107. How would you measure the working distance of a projection lens?

MEASURING EQUIVALENT FOCUS, PAGE 200

108. Describe the process of measuring the equivalent focus of a projection or other compound lens.

WORKING DISTANCE AND LENS DIAMETER, PAGE 201

109. Is the working distance and the lens diameter often of great importance?
110. How may the projectionist ascertain whether or not the beam all enters the projection lens?
111. If a plano-convex condenser is used will the beam enter the lens in its entirety?
112. How may the divergence of a beam be reduced and what is the objection to doing it?
113. How may projectionists discover that unevenness of screen illumination is inevitable if the light does not all enter the lens?

PROJECTOR OPTICAL TRAIN, PAGE 205

114. Of what does the projector optical train consist?
115. Describe the function of the first element of projector optical train.

116. What is the function of the second element of the projector optical train?
117. What is the first point of efficiency to be considered?
118. What is the effect of increased distance of the light source from the collector?
119. What limitations govern the distance of the light source to the collector?
120. What difficulty does the thin-edge, thick-center collector lens set up when working with a high-power electric arc?
121. What is one effect of a heavy arc tail-flame?
122. How may the collector be guarded from some portion of the tail flame heat?
123. What should the focal length of a plano-convex condenser collector lens always be?

Lens Pitting, page 207

124. How are collector lenses pitted and is there any practical way of preventing it?

The Collector, page 208

125. What should be the focal length of the collector of a plano-convex condenser?
126. What should be the focal length of a converger?
127. Why should convex surfaces be placed next to each other in plano-convex condensers?

Spacing Condenser Lenses, page 208

128. Why should condenser lenses be as close together as possible without actual contact?
129. Does the collector of a plano-convex condenser send forward a parallel beam of light?

The Converging Lens, page 208

130. Upon what is the spot diameter dependent?
131. How should the projectionist select his condenser?

Mirror Collector Converger, page 209

132. What office does the mirror collector serve?
133. Describe the effect of spherical aberration in such mirrors.
134. Do all such mirrors have this fault?
135. May spherical aberration in such mirrors be corrected?
136. What constitutes the parabolic or the elliptical mirror?
137. What is the practical effect of spherical aberration?
138. Is spherical aberration detrimental to good projection?
139. Will a properly installed mirror converger collect more light than the 4½ inch diameter plano-convex condenser?
140. Examine Figs. 91 and 92 and explain the points raised in the text covering them.
141. Is the mirror a more efficient collector of light than the plano-convex condenser?
142. Name one reason why the reflector type arc produces a hotter spot than an arc with which a plano-convex condenser is used.
143. Name one advanatge of locating the rotating shutter between the light source and the aperture source.
144. Is the mirror an efficient light collector as compared with the glass condenser?
145. Explain the real cause of spherical aberration in a spherical mirror working with a projector light source.
146. How may spherical aberration be corrected?
147. Explain the reduction or enlargement of the spot diameter caused by advancing or retarding the light source from the mirror.
148. What two surfaces present the highest possible accuracy and efficiency in light reflection?
149. What is placed on the back of the mirror?
150. What backing is applied on top of the silver?
151. Is it essential to locate the light source at a certain fixed distance from the mirror surface, and the mirror a fixed distance from the aperture?
152. What is the distance from the light source to the mirror vertex called?
153. What term is applied to the distance from the mirror vertex to the aperture?
154. Must mirror focus and mirror working distances be maintained exactly?
155. Are these distances different for mirrors of different focal lengths?

156. How closely must these distances be maintained?
157. What types of glass are best for mirrors?
158. Name two points essential to efficient operation of mirrors
159. How often should mirrors be wiped off?
160. What cleaning fluid is best for mirrors?
161. How should mirrors be cleaned when a flaming high intensity arc is used?
162. How often should the mirrors be removed for washing and how should they be washed?
163. What should be done when the silver tarnishes?
164. What should be done if the mirror is pitted or scratched?
165. Is it profitable to continue to use a scratched or pitted mirror?

TREATED LENS SURFACES, PAGE 217

166. How much light may be lost by reflection in a compound projection lens?
167. Is any glass 100% transparent, or does all glass reflect some of the light that falls on it?
168. Give two reasons why reflection light loss in a projection lens is undesirable and harmful.
169. How can reflection light losses be reduced?
170. How is the surface-treating process controlled?
171. Can surface treating be applied to any projection lens, even one manufactured long ago?
172. What are two practical advantages of treated surfaces?
173. What precaution must the projectionist observe in connection with treated lenses?

CHAPTER IX

LENSES AND MIRRORS

(1) Before the projectionist can hope to deal intelligently with lenses and their action upon light, he must understand certain basic laws, one of which has to do with light intensity at varying distances from an open light source. It reads:

(2) "Light intensity decreases inversely as the square of the distance from its source."

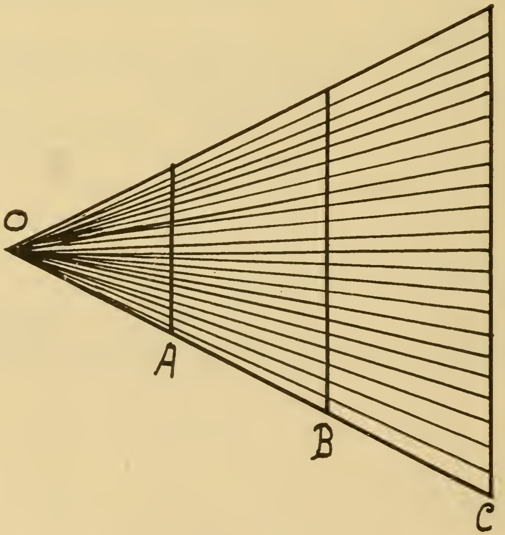


Figure 75

(3) In Fig. 75 we see an open light source with three screens, A, B and C, located one foot, two feet and three feet respectively from the light. Screen A, we will assume, is exactly one foot high and one foot wide. It therefore represents one square foot of area. Screen B located two feet from the light, has twice the dimensions of screen A and is 4 feet square. Screen C is 3 feet

from the light source and is 3 feet wide by 3 feet high and is therefore 9 square feet in area. A fourth screen located 4 feet from the light source reaching to the same boundary lines would be 4 feet high, and if it were also 4 feet wide would have 16 square feet of area.

(4) Light travels in perfectly straight lines through any transparent medium that is of even density throughout.

(5) It changes its direction only upon encountering a medium of different density at an angle.

Barring a change of direction the rays will travel as indicated by the black lines within the space bounded by the outer lines so that if screen A is removed the rays will cover screen B exactly and if both screens A and B are removed, they will cover screen C, and so on indefinitely.

(6) Considering these facts we discover that, since screen B has four times the area of screen A, doubling the distance quadruples space the rays will cover. The illumination of screen B will be only one-fourth as brilliant as screen A, assuming that both screens have equal powers of reflection. Stated differently, the surface of screen B is four times as great as that of screen A. The light has equal power of illumination at both screens but at screen B it is spread over four times as much surface. Hence the illuminating power per unit area is decreased in the ratio of four to one. If another screen square in shape and reaching to the same diverging boundary lines were located four feet from the light source, it would be 16 square feet in area. The ratio of decrease in illumination would then be 16 to 1. An understanding of this law is especially important in connection with the distance of the light source from the collector lens or mirror.

(7) Projectionists are called upon to handle very difficult optical systems. This is particularly true of the motion picture projector, in which two separate optical systems are combined, one of them highly "corrected" and one either not corrected at all or only partially so. (8) These systems are so joined that the first picks up

diverging light rays from the light source, converges them upon the projector aperture near which it forms a more or less out of focus image of the light source. This

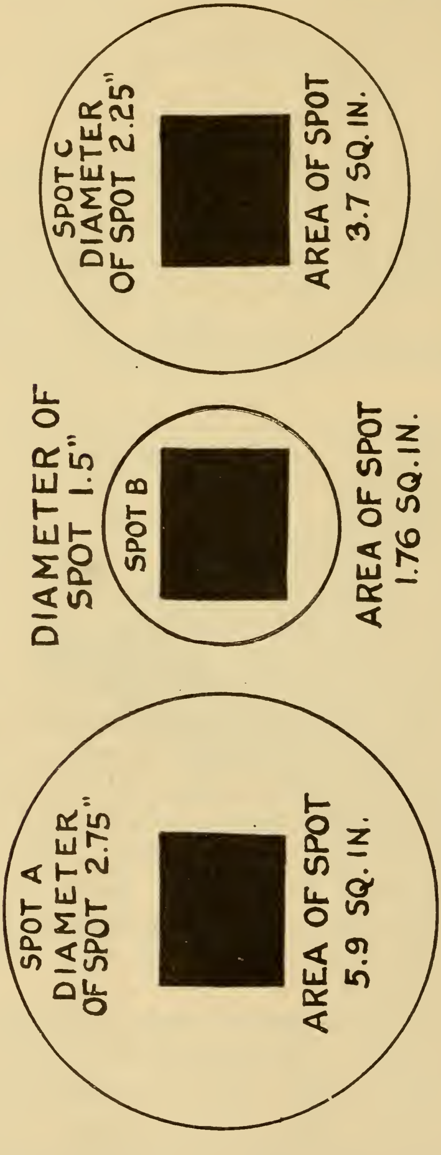


FIG. 76.—Illustrating the possibility of loss of light at a given point. Total light passing through apertures Spot A, 13%; loss of light at Spot A, 87%. Total light passing through apertures Spot B, 43%; loss of light at Spot B, 57%. Total light passing through apertures Spot C, 19%; loss of light at Spot C, 81%.

system may be either a single lens glass condenser, a 2-lens glass condenser or it may be a spherical, an elliptical or a parabolic mirror, working either with or without a converging lens of glass.

(9) The second system consists of a projection lens (a compound lens, usually made up of two elements separated slightly by a metal spacing ring and two other elements cemented together with Canadian balsam, the whole contained in a brass barrel) which picks up a bundle of light rays emanating from every one of the tens of thousands of pin points in the film photograph posed over the projector aperture. This lens receives and so refracts the rays that each reaches exactly its appointed place in the screen image they combine to form. Thus the enormously magnified image is sharp and clear when viewed from a reasonable distance.

DEFINITIONS

Some definitions are given below that are important to a practical understanding of the optics of motion picture projection.

Angle of Incidence

(10) Angle a light ray forms with a line at right angles to any surface at the point of contact.

Angle of Refraction

(11) Angle a light ray forms with a line at right angles to the surface of lens at the point of entering or leaving it.

Barrel Distortion

(12) Uncorrected lenses so distort straight lines in the screen image that they are more or less curved.

Bi-Convex Lens

(13) A lens that is convex on both sides. See Figure 77 on page 186.

Brilliancy

(14) Intensity of illumination as measured in foot candles.

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Collector Lens

(15) The lens of a 2-lens condenser that is next to the light source and therefore collects the light.

Compound Lens

(16) An assemblage of lenses mounted to form one lens.

Conjugate Foci

(17) A term having reference to two points, one of which is the light source or an object, the other the point at which the image of such light source or object is formed. It is the distance of the optical center of the lens from each of these points. If the distance to one of these points is altered, the other also is automatically altered. If one is moved nearer the lens the other will automatically be moved further away.

Converging Lens

(18) The lens of a 2-lens condenser that is located farthest away from the light source. The lens that converges the light upon the projector aperture and cooling plate. The prismatic condenser and the mirror, when used, act as both collector and converger, except where a mirror is used in conjunction with a lens, as is done in one equipment.

Condenser

(19) In projection optics, a lens or combination of lenses by means of which rays from the light source are collected and converged upon the projector aperture and cooling plate.

Chromatic Aberration

(20) An uncorrected lens, or an improperly corrected lens, tends to separate white light into its component elements or colors, focusing the colors at different distances from the optical center of the lens. This fault is corrected by combining lenses of crown and flint glass having convex and concave surfaces. In other words positive and negative lenses.

Equivalent Focus

(21) A term (commonly abbreviated as E. F.) used only with relation to lenses having two or more elements, of which the projection lens is an excellent example. In effect it means that the lens, viewed as a whole, has the same power of magnification or reduction as a simple lens having the same focal length as the E. F. of the compound lens.

(22) Although the simple, uncorrected lens possesses such faults as spherical and chromatic aberration and cannot project the same sharp image that a corrected compound lens does, these faults do not, in any degree, alter the focal length of the simple lens.

Critical Angle

(23) Light passing through a transparent medium of one density will, upon contacting a transparent medium of greater density enter it, but with a certain percentage of reflection loss. If, however, the angle of incidence is too great, the light will not leave the lighter medium and enter the heavier. Instead it will be reflected from the surface of the heavier medium in its entirety. The critical angle varies with different mediums. It is approximately 41° between air and polished glass.

Focal Length

(24) Distance between optical center of a lens and the object when its image is in sharpest focus.

Free Diameter

(25) The diameter of a lens that is free and open to the passage of light.

Incident

(26) Optically "incident" means contact. "Light is incident upon" means it is in contact with some surface.

Lens Correction

(27) The grinding of lens surfaces and the combining lenses of glass of different refractive indices so that

spherical aberration, chromatic aberration and other faults inherent in simple, single lenses are corrected.

Light Ray

(28) A thin line of light having no appreciable area of cross section.

Meniscus Lens

(29) A lens having one convex and one concave surface. A lens that tends to diverge rays of light leaving it. See Fig. 77.

Perpendicular

(30) Optically, perpendicular means at right angles to.

Plane

(31) As applies to a lens, a line passing through its diameter exactly at right angles to its principal axis.

Plano Convex Lens

(32) A lens that is flat on one side and convex on the other. See Fig. 77.

Principal Axis

(33) An imaginary line passing through the exact center of a lens precisely perpendicular to its plane.

Projection Angle

(34) The angle between the axis of the projected light beam and a horizontal line.

Refraction

(35) The bending of light rays caused by leaving a transparent medium of one density and entering a transparent medium of different density. Refraction is based upon the following law: Light rays travel in perfectly straight lines through any transparent medium of uniform density. They are refracted (their course altered) in the act of leaving one medium and passing into another of different density, provided entry into the second medium is at an angle to its surface. There is no refraction if the angle of incidence is zero.

Simple Lens

(36) A single, uncorrected lens.

Spherical Aberration

(37) That quality of an uncorrected lens that focuses light rays passing through its various zones (at different distances from its axis) at different distances from the optical center of the lens. The further from the axis a ray passes through, the closer to the lens it will be focused.

Working Distance

(38) As applies to a projecton lens, the distance from surface of photographic emulsion on film, when it is in position over the projector aperture, to rear or first surface of the lens.

(39) There is a difference between "working distance" and "back focus," with which it is often confused. "Back focus" is a technical term indicating the distance of film emulsion to first surface of the lens when light rays illuminating the aperture are parallel—a condition never found in projection. Back focus therefore is a term that cannot be used correctly in the lexicon of projection optics.

Lens Action

(40) The action of lenses upon light is based upon the principle that if a ray of light, on passing through a transparent medium of one density encounters the surface of another transparent medium of heavier or lighter density, at an angle, and enters it, the course of the ray will be altered. How much the ray will be "refracted" in passing at an angle into the medium of different density depends upon (a) the difference in density of the two mediums and (b) the angle at which the surface of the second medium is met.

(41) From the optical engineer's viewpoint each tiny pinpoint of a curved lens surface presents an entirely separate proposition from every other pinpoint of the lens surface, even though the two points join each other. Each point presents a different angle to light rays than

any other point, even though it is an adjoining one. Each point therefore refracts an incident light ray in a different direction than do all other points.

(42) In passing through the lens surface upon entering, the light ray receives its initial refraction. The amount of refraction depends upon the angle of incidence and the refractive index of the glass. If the glass is homogeneous (of even density throughout) the light will pass through it in perfectly straight lines until the opposite surface of the lens is reached. If the light reaches the second surface at an angle (as it must unless it was incident upon the first surface at the axis of the lens, and perpendicular to the surface at that point) the ray will again be refracted in passing from the lens.

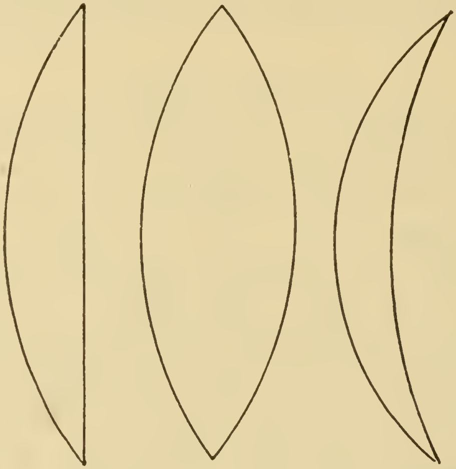

FIG. 77.—Left, plano-convex; center, bi-convex; right, meniscus lens.

(43) From this we perceive that if a lens is homogeneous its action upon light may be ascribed to the following elements: (a) the refractive index (density) of the glass; (b) the angle at which the lens surface is met at both of its surfaces; (c) the relative density of the medium through which the light passes before it reaches lens and (d) the lens itself.

(44) If a light ray meets a lens surface exactly at

right angles both upon entering and leaving, it will pass straight through without being refracted in any degree. There will be loss at both surfaces through reflection, that will vary widely with the perfection of polish and the cleanliness of the surfaces.

(45) Where the ray meets the lens surface at an angle there is not only refraction but also greater reflection, both refraction and reflection increasing as the angle of incidence increases.

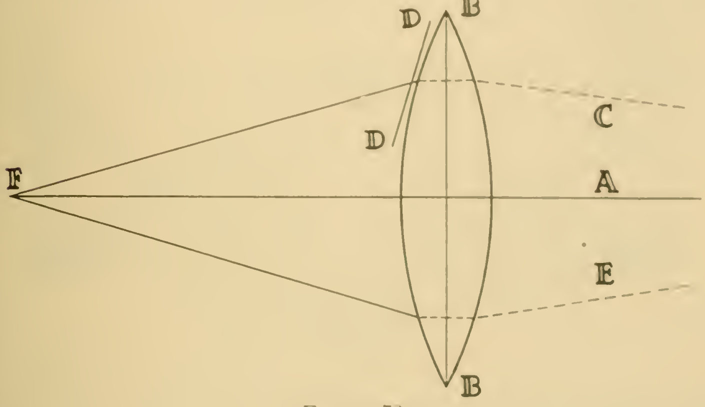

FIGURE 78

(46) Fig. 78 shows a bi-convex lens. FA represents the principal or optical axis, BB the plane of the lens and F is a point representing the center of a circle which the lens surface furthest away would form if the line representing its surface were continued; DD is a line representing the plane of the curved surface of the lens at the exact point ray FC enters; FC and FE are light rays.

Were FA a light ray, since it both enters and leaves the lens perpendicularly to both surfaces, it would not be refracted and would pass through straight as shown. Ray FC enters the lens at a considerable angle. The air and glass being of different density, the ray is refracted somewhat as shown by the dotted line; it passes straight through the body of the lens until it meets the second surface, also at an angle, whereupon it is again refracted, usually less than at the first surface because the angle of incidence is generally less. There is a loss by reflection at both surfaces.

Exactly the same action occurs with ray FE, and with all other rays incident upon the lens, refraction varying with the angle of incidence of each ray.

Image Formation

(47) All rays emanating from object X, in Fig. 79, that reach the surface of the lens will be refracted to meet again (be focused) at a point in image Y that corresponds to object X. At the image point the rays may spread over a larger or smaller area than they occupied at the object—the image being either magnified or diminished. Points X and Y are the conjugate foci points of the lens.

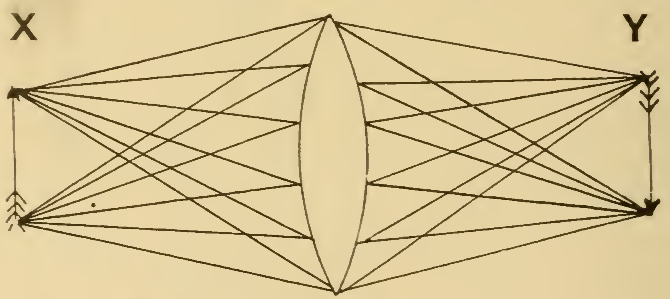

FIGURE 79

If object X is moved nearer the lens, image Y is automatically moved further away and magnified. If object X is moved further away, image Y is moved nearer the lens and reduced in size. If object X is moved up to the focal plane of the lens (separated from the lens by its focal length) Y is at infinity—that is to say, infinitely far away. If X is moved closer to the focal plane of the lens, Y is lost, the rays leaving the lens in diverging lines.

It is this law that is operative when the projection lens is moved backward or forward to focus the image sharply. In so doing the conjugate foci points are altered, though one of them only slightly. Remember that the distance to one conjugate foci point (optic center of lens to film) is very short, while the distance to the other (optic center of lens to screen) is very long; therefore a very slight alteration of the shorter conjugate foci point will have large effect upon the longer one.

Lens Correction

(48) All uncorrected lenses have spherical and chromatic aberration, as well as other faults. The aberrations may be eliminated by various combinations of glass and curvatures.

Focal Length

(49) The focal length of a simple lens is the distance from its optical center to the center of the image it forms when the image is in sharpest possible focus and the object being focused is sufficiently distant so that light rays enter the lens in essentially parallel lines.

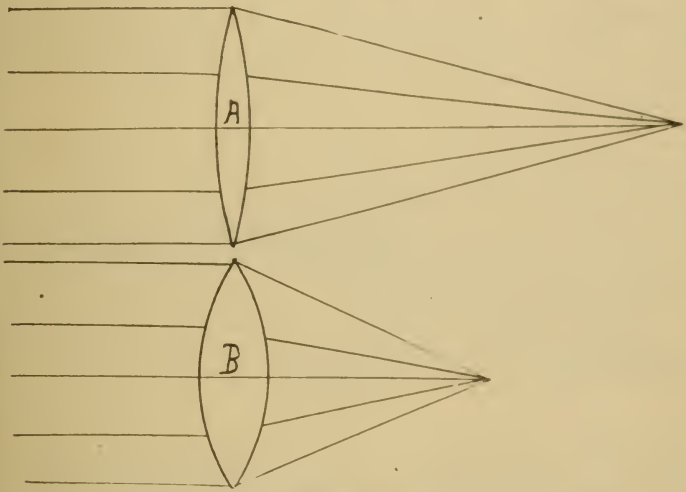

FIGURE 80

(50) The focal length of a lens is somewhat affected by the refractive index of its glass, but chiefly by the curvature of its surfaces. This is illustrated in Fig. 80, wherein we see two simple lenses in which the fault of spherical aberration has been disregarded. The actual performance of such lenses is shown in Fig. 81. It does not alter the focal length of the lens in any degree.

It is observed that the lens having the greatest surface curvature focuses parallel light rays nearest its plane.

Lens Curvature

(51) Each surface of such lenses as are shown in Fig. 80 are exact duplicates of the curved surface of a disc cut from a polished glass ball having a diameter roughly equal to the focal length of the lens. Thus, a 4½ inch diameter, 7½ inch focal length plano convex lens would approximately duplicate a 4½ inch diameter section cut from a polished glass ball 7½ inches in diameter and afterward polished on its flat side. Were the diameter of the ball 6½ inches, then such a disc cut from it might be a 6½ inch focal length plano convex lens. Were we to grind the flat side into concave form, the lens then would be what we term a "meniscus" lens.

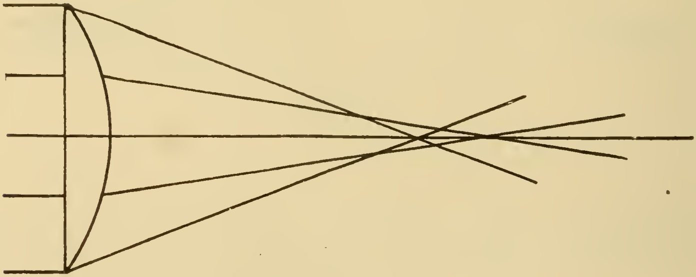

FIGURE 81

(52) Place two plano-convex lenses together and we have a bi-convex lens, examples of which are shown in Fig. 80. The refractive power of a bi-convex lens is double that of a single plano convex lens of equal surface curvature.

(53) Fig. 81 conveys visually the effect of spherical aberration. Examining it you will observe that rays passing through the lens close to its principal axis focus much further away from the lens plane than do the rays passing through its outer zones.

This effect is progressive from the principal axis to the outer margin of all simple lenses.

(54) Spherical aberration in simple lenses such as

are used for glass condensers has considerable value because it serves to "break up" the image of the light source, which never has even luminosity over its entire area. Spherical aberration has some value in preventing the image from being projected to the screen in the form of uneven illumination.

Lens Cannot Focus to a Point

(55) Unless the light source be infinitely small—a pinpoint, in fact—a lens cannot possibly focus light coming from it to a point. A lens focuses light rays to form an image of a light source or object and the image may be either smaller, larger or of equal size with the light source or object. (56) Stating it another way, rays are sent forth from every pinpoint of a light source, or from an object from which light is reflected. Rays from this pinpoint and from every other pinpoint of the light source or object are picked up by every section of a lens within their view which usually means its entire area. These rays are refracted by the lens and sent forward to a screen placed exactly at the other conjugate foci point of the lens, where they are refocused to a point which may, however, be larger than the point from which they come. Millions of these refocused points, each in its exactly appointed place, constitute an image of the object or light source from whence the rays emanate.

The Projection Lens

(57) The projection lens is known as a compound lens, which is a lens having more than one element. It has four lenses in fact, though two of them are usually cemented together with Canadian balsam. At the rear of the lens (end next the film) are two lenses, usually separated slightly by a spacing ring. At the other end of the lens barrel is the "front element," consisting of the two lenses cemented together. At a superficial glance they will appear to be one thick lens.

(58) Sometimes the Canadian balsam, with which the lenses are cemented together, will melt, producing a

streaked effect in the screen image. In such case the lens must be returned to its maker for repair. It is a job that cannot be done by the projectionist without danger of disturbing the lens corrections.

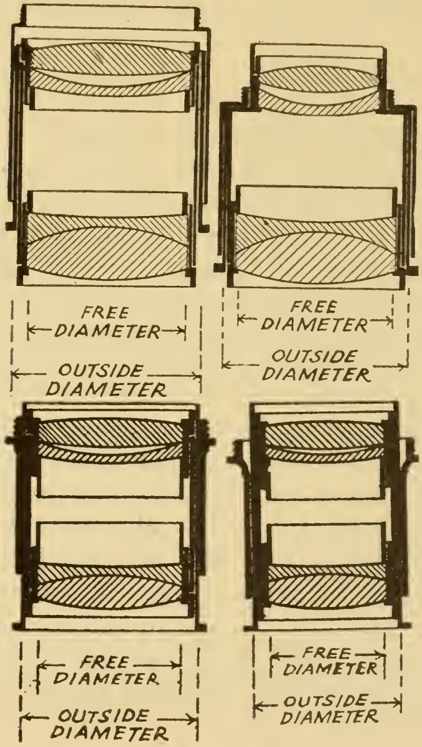

Fig. 82.—Sectional view of projection lens elements and their mountings.

(59) Some lens manufacturers employ a design in which the rear element (rear lenses) is the cemented combination, giving a long lens. The rear element is located much closer to the aperture than is usual in lenses having the front elements cemented. This design locates the cement considerably closer to the point of greatest heat concentration and consequently it is subjected to steady deterioration.

Repairing Lenses

(60) If one element of a projection lens is injured, the manufacturer can replace it. Send him the entire lens including the broken parts of the element to be replaced. (61) This will enable him to restore the lens to its exact original focal length.

(62) Odd lenses taken from old compound lenses have no value. They could be utilized only in building a new lens, but it would cost more than a good stock lens.

Ordering Lenses

(63) When ordering projection lenses supply the following data: (a) Kind of light source—filament,

straight arc, reflector type, high intensity or high intensity reflector arc. (b) Exact width of the picture at the center of its vertical length if there is any projection angle. (c) Projection angle. (d) Exact distance from the center of the screen to projection lens center. (e) Make of projector. (f) Width of projector aperture, in thousandths of an inch. The aperture width may be procured from the manufacturer of the projector, or it may be measured with the proper tool. If an exact measurement cannot be made, nor the lens sent, then tell the lens manufacturer the exact type of aperture used. (g) Specify lenses without jackets.

RANGE OF FOCAL LENGTHS

(64) Projection lenses of the following standard focal lengths are carried in stock by manufacturers and by some dealers. Figures represent equivalent focus.

Quarter Size

Series I: 3, 3¼, 3½, 3¾; 4, 4¼, 4½, 4¾; 5, 5¼, 5½, 5¾; 6, 6¼, 6½, 6¾; 7, 7½; 8.

Half Size

Series II: 5, 5¼, 5½, 5¾; 6, 6¼, 6½, 6¾; 7, 7½; 8, 8½; 9.

Super Cinephor Lenses

Mounted in quarter size barrels: 2, 2¼, 2½, 2¾; 3, 3¼, 3½, 3¾.
Mounted in half size barrels: 4, 4¼, 4½, 4¾; 5, 5¼, 5½.

The above data—used merely as an illustration—covers Bausch and Lomb lenses only. Statement of focal lengths, etc., can be secured direct from other lens manufacturers upon request.

The so-called "quarter size" projection lenses are manufactured in focal lengths from 3 to 8 inches. E. F. Beyond 7 E. F. they may be had only in two sizes: 7½ and 8 inches E. F.

The new anastigmatic projection lenses, such as the Super Cinephor, are available in one-quarter inch focal length from 2 to 5½ inches E. F. The expressions "quarter and half sizes," of Series I and II, are no longer used in describing the Super Cinephor lenses. Every effort is being made in this line to approximate constant speed, as in the anastigmatic photographic lens design, in which the glass elements become larger but the same speed, so far as possible, is employed.

Matching Lenses

(65) Should you wish to obtain a projection lens to match the one you have, it is best to send the lens to the manufacturer. (66) If you cannot do that, then send him the precise width of the projector aperture opening, measured in thousandths of an inch; also the exact distance from the lens center to the screen at the center of the vertical height of the screen image (with no film over aperture): also the exact projection angle. Do not rely on lens markings as they have an allowable tolerance of error which makes them only approximately reliable.

(67) One lens manufacturer has an excellent method of marking his product. When a lens is finished, the E. F. is very carefully measured. If the E. F. is exact in focal lengths it is marked on the barrel as 5-inch, 6½-inch, etc. If the lens is a trifle more or less than the prescribed focal measurements, but is within plus or minus of one percent of the computed E. F., a plus or minus sign, as the case may be, is engraved in addition to the measurement. (68) All lenses marked without a plus or minus are considered as matched lenses, having even focus. The total difference in picture dimensions of a lens marked 6″— and one marked 6″+ would not in any case exceed 1 to 1.5 inches, which may be absorbed by the black border.

Light Loss By Reflection

(69) Optical engineers estimate that the light reflected from clean, well polished glass surfaces is from 4 to 5 percent at each surface where the light meets the surface perpendicularly. It is higher where the light meets the surface at an angle, and increases as the angle becomes more acute. Some optical systems have as many as ten glass surfaces through which the light must pass—each one of which reflects its quota of light. (70) There are heavy losses at other points—at the spot and at the rotating shutter, the latter eliminating approxi-

mately half the light at one swoop. Deposits of dust and scum gathered from the air also cause loss of light (by reflection).

It is easy to see how important it is to keep all lenses scrupulously clean and well polished. (71) Loss of light is not the only evil effect of dirty lenses. Deposits of dust and dirt disperse or diffuse and misdirect a portion of the light rays and as a result the lighter shades in the screen image are made still lighter and the blacks become a dirty gray. The picture, instead of being "snappy" is dull.

Cleaning Lenses*

(72) Oil on a lens surface seriously injures the definition (focus) of the screen image. Oil, once deposited, spreads around. (73) A slight finger mark, so faint it cannot be seen by looking through the lens, may blur definition. (74) Such marks usually may be seen by looking at the glass surface sidewise.

(75) There are many lens cleaning preparations on the market, but best of all is a soft cloth and a mixture of half clean water and half grain alcohol. Do not use denatured alcohol as it leaves a scum on the glass. Clean the lens when it is cold. Be careful not to touch the lens with your fingers after cleaning it.

(76) Lenses should be examined at least once each day. (77) Mirrors or condensing lenses should be cleaned each morning while they are cold.

(78) At regular intervals, lenses should be disassembled, the coating on the interior of their barrels examined and the lens surfaces cleaned. (79) The interior coating of the barrel is dull black to prevent reflection of light. (80) If it wears or peels off so that the metal shows, it should be recoated immediately, using coach painters' black thinned with turpentine. In reassembling lenses, each element must be replaced with its heaviest curvature toward the screen end of the lens.

(81) One lens manufacturer tapers the various lens edges so that they cannot be replaced wrongly. Some-

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* For cleaning treated lenses, see Page 218.

thing of this sort should be done by all projection lens makers. (82) Projectionists who have lenses in which the elements can be wrongly assembled will do well to secure a bottle of waterproof draughtsman's ink, black or red in color, and as they disassemble the lenses for the first time, put a small spot of ink on the face of each lens just at its outer edge on the screen side. The spot should remain indefinitely. The ink or other mark must be near enough the lens edge to be hidden by the retaining ring.

(83) Exercise care and patience in disassembling. The retaining parts have very fine threads and are for the most part rather light. They may be bent out of shape quite easily. Do not attempt to force them by using a screwdriver point or other heavy instrument. Unthread with your fingers if it is at all possible to do so.

(84) When reassembling clamp each separate lens into its retaining mount snugly, but be very careful not to set the holding element up too highly. If you do, it will make it difficult to disassemble the lens again when necessary. It will be sufficient to set the ring up so that the lens does not rattle audibly when shaken. Screw the retaining mounts into the barrel as far as they will go. Failure to do this will disturb both the E. F. and the corrections of the lens.

Loss Through Absorption

(85) Glass used in modern projection lenses absorbs but a small percentage of the light as it passes through the body of the glass itself. Absorption of good crown glass is given as 1 to 1.5 percent per centimeter (.3937+ of an inch) of distance covered by the light. Flint glass absorption is just a little higher. (86) Poor quality glass may absorb as much as five percent of the light per centimeter of thickness. Since condensing lenses of the ordinary plano convex 4.5-inch diameter type are thick, it is apparent that a condenser lens made of good grade glass is to be preferred to one of poor quality glass which absorbs light excessively.

BARREL OR PINCUSHION DISTORTION

(87) Barrel distortion in a lens causes it to project a straight line in the form of a more or less pronounced outward curve. Pincushion distortion causes the lines to bend inward. (88) Following is a test for either fault. New lenses should be subjected to it immediately.

(89) Open the projector gate and project white light to the screen. Stretch a cord lightly along the edges of the light. If the edges are straight there is no barrel or pincushion distortion. If the edges bend outward there is barrel distortion. If the edges bend inward there is pincushion distortion.

TESTING FOR FLATNESS OF FIELD

(90) It is very easy to test a lens for its ability to produce flatness of field (sharp definition of "focus") all over the screen surface, yet apparently few projectionists know how to do it.

First, prepare a light wooden frame two or three feet square. Stretch white paper or cloth over it tightly. Select a film scene in which you are certain the photographic focus is sharp. Project it and sharpen focus as critically as possible at the screen center. Examine one corner of the screen image carefully. If the definition at the screen center and corner is equally sharp, then the lens has passed the test for flatness of field. But if the definition at the corners is less sharp than at the center, then hold the small screen in the proper position in relation to the light beam and advance it slowly toward the lens, while a second person observes the definition from the front. When a point is reached where the definition at the corners is as sharp as the screen center, the point represents the outer end of the arc of a circle that would touch the screen surface at its center. It represents the curvature of the screen surface necessary to secure sharpness of definition (focus) over its entire area. It therefore shows exactly how much the lens under test fails to produce flatness of field.

Why and Wherefore of Focusing

(91) From every pinpoint of the film photograph posed over the projector aperture, millions of diverging light rays go forward in the form of a cone, the taper of which is dependent upon the focal length of the condenser or reflecting mirror and its distance from the aperture. (92) It is the function of the lens to collect these rays from every pinpoint of the photograph, and to refract them so that they will converge and focus at similarly placed but enlarged points upon the screen. The film represents one conjugate foci point of the projection lens, the screen the other. (93) If the distance of the lens from the film is altered in any degree by means of the focusing screw, or by other means, the definition or focus of the screen image is changed.

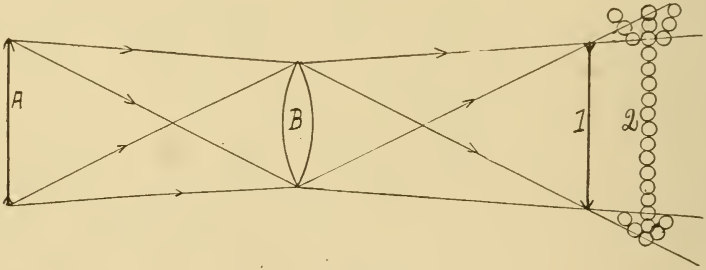


Figure 83

(94) In Fig. 83, we find an explanation. A, being the film, B the projection lens and 1 the screen, it is observed that at 1, the point of focus, the rays emanating from the film photograph meet and cross. If the screen were at 2 instead— and not at 1—the rays would not focus at 2 unless the conjugate foci points were altered. On this plane each point would appear as a circle and the whole image would be badly blurred. When the screen image is blurred it indicates that the rays are focused at a point or plane either before or behind the screen surface. The lens must then be moved slightly backward or forward, altering the conjugate foci points so that the rays focus exactly at the screen surface of the plane.

(95) Depth of focus is definitely a physical condition.

(96) It is in exact proportion to the speed (diameter) of a lens and its focal length. (97) All lenses having equal quality of correction, equal focus and equal diameter will have exactly the same depth of focus.

ALTERING LENS FOCAL LENGTH

(98) It is impossible to alter the E. F. of a lens by lengthening or shortening the distance between its front and back factors—by lengthening or shortening the tube in which they are mounted—without, at the same time, destroying its maximum efficiency. It is a bad practice.

PICTURE SIZE AND E. F. OF LENS

(99) Any lens will project a picture any practicable distance, but (100) a lens can project a picture of given dimensions at one, fixed distance only. If it projects further, the picture dimensions will be increased and vice versa. Any alteration of projection distance automatically alters the working distance of the lens. (101) The greater the E. F. of the lens the longer will be its working distance—distance of the surface of the rear lens to the aperture. Moving one conjugate foci point further from the lens automatically moves the other closer to the lens.

MEASURING FOCAL LENGTH

(102) Due to spherical aberration and other faults of simple lenses, the projectionist cannot measure their focal length accurately unless he uses a gauge for measuring lenses in diopters. With this instrument, focal length in inches is easily calculated. (103) He may, however, measure their focal length for all practical purposes by another means—crude but sufficiently accurate.

(104) To measure the focal length of a plano convex lens proceed as follows: Select an open window from which some object not less than fifty feet nor more than one hundred feet distant is visible. To the wall opposite the window pin a sheet of white paper. Hold the lens with its flat side toward the screen and parallel with its

surface. Focus the distant object as sharply as possible on the paper screen, while an assistant measures the distance from the flat side of the lens to the screen. Reverse the lens, holding its convex side toward the screen and the flat side parallel with the screen's surface. Again focus the object sharply and measure the distance from the flat side of the lens to the screen. Add these two measurements and divide by 2. The result will be a close approximation of the focal length of the lens.

(105) Bi-convex lenses may be measured the same way. Focus a distant object sharply on the paper screen and measure from the center of the lens edge to the screen surface. That will be the focal length of the lens, provided the lens has been held parallel with the screen surface.

Focal Length of Simple Lenses

(106) Be sure the lens is perfectly clean. Hold it parallel with the screen so that its edge all around is equi-distant from the screen surface. Focus an object no less than 50 feet away. An object 100 feet or more away is better since it allows the light to enter the lens in essentially parallel rays which leads to more accurate conclusions. The room should be as dark as practicable when making the measurement, because too much light makes it difficult to judge the sharpness of focus.

Measuring Working Distance

(107) To measure a working distance, first focus the picture as sharply as possible on the screen. Stop the projector, remove the film and measure the exact distance from face of the tracks upon which the film rests in passing through the gate, to the first surface of the lens. If the uncoated side of the film is next to the aperture the thickness of the film must be added for exact accuracy. This measurement is the working distance often wrongly referred to as "back focus."

Measuring Equivalent Focus

(108) This is seldom necessary but easy to do. Use two sheets of black or dark colored paper a few inches

square. In one sheet cut a hole one inch square or smaller. Trace the outline of this hole on the other sheet. Mount the opening in the dark paper over a hole cut in a large sheet of opaque wrapping paper. Next suspend the wrapping paper over an open window and with the help of two assistants, focus the lens on the opening until its image exactly fills the space within the traced outline on the second black sheet. Measure the exact distance from wrapping paper to the second black sheet. Divide the sum by 4 and the result is the E. F. of the lens.

WORKING DISTANCE AND LENS DIAMETER

(109) When using certain types of condenser, working distance and lens diameter become important items in obtaining even screen illumination and in avoiding waste of light. The projectionist may determine whether or not the condition is correct with a little effort.

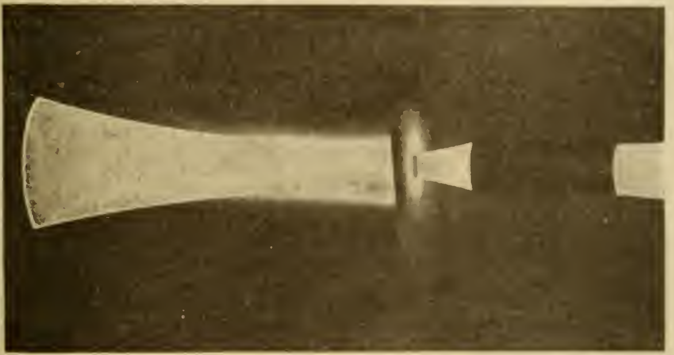


FIGURE 84

(110) Open the projector gate and remove anything which obstructs the view of the aperture and the lens. Project a white light to the lens and blow smoke into the mechanism casing. Instantly the light beam will become sharply visible and its exact diameter where it meets the lens may be observed. Do not run the mechanism during the operation as air disturbance by the projector shutter will make the view of the beam less distinct. Hold a white paper or cloth at the rear end of

the lens and observe the beam diameter that way if you prefer.

(111) If a plano-convex condenser is used the beam will be as in Fig. 84. It may or may not all enter the lens. (112) If it does not, a lens of larger diameter is needed although other considerations may make it impractical. A longer focal length converging condenser lens may increase the distance between the condenser and the aperture, and thus reduce the spread of the beam beyond the aperture. Increasing the focal length of the condenser will automatically increase the distance of the light source from the collector lens, and thus set up a loss which may neutralize any gain, but any reduction of the spread of the beam between the aperture and lens will tend to make the screen illumination smoother even if the beam is not all entering the lens.

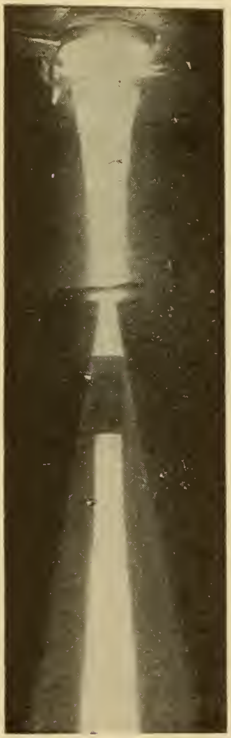
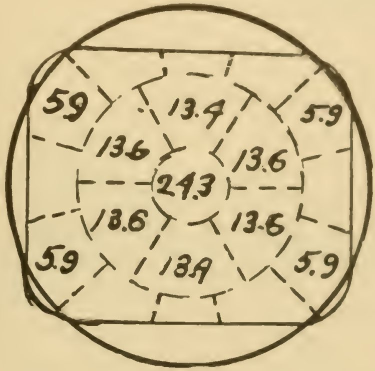


FIGURE 85

In Fig. 85, a photograph with light made visible by smoke, we see how the light beam overlaps the lens.

(113) Any projectionist may ascertain for himself by means of a simple, convincing experiment whether this sets up uneven light distribution on the screen. Secure a small sheet of stove pipe or other thin flat metal. Cut out a strip about three inches long the width of a film. On its surface lay out two frame lines the same shape and size as those on film. Lay this on a freshly sawed block of wood, end-of-grain side up, and with a punch filed to a sharp point, punch a small hole exactly in the center of one of the "frames" and near one (either) corner of the other.

Now place the metal strip over the aperture with the center hole in the center of the aperture. Centering the hole is important, though if it is within 1/16 of an inch of the center it will do. Block up the automatic fire shutter and project a white light through the hole. Blow smoke into the tiny light beam (projector is not running) and you may see just what area of the lens the beam covers. Probably all of it will be found to enter the lens, which, of course, indicates that all the light passing through the center zone of the film enters the lens and consequently the central portion of the film is fully illuminated on the screen.



Exact Size and Shape of Ray Three Inches from Aperture When Condenser is 18 Inches from Aperture.

Zone	Area	Avg. F.C.	Lumens	% Total
1	.0079	24.3	.19	10.8
2	.062	13.5	.86	49.2
3			.70	40.0
		Total	1.75	100.

FIGURE 86

Now place the other "frame" over the aperture, so that the hole will be at one corner of the aperture instead of at its center. Again blow smoke and observe the condition. If the whole cone of light enters the lens, well and good. If it does not, then it is plainly evident that the light incident upon the outer zones of the film does not all enter the lens and hence there is unevenness of screen illumination. Fig. 87 is a graphic illustration of the experiment.

Fig. 86 illustrates the fact that the light beam between the projector aperture and the lens does not always have an even light intensity. It sets forth the intensity of light at various sections of the beam, as measured for the BLUEBOOK by Eastman Kodak engineers. Light values have changed widely, but light distribution, as shown in Fig. 86, has not altered in any appreciable degree.

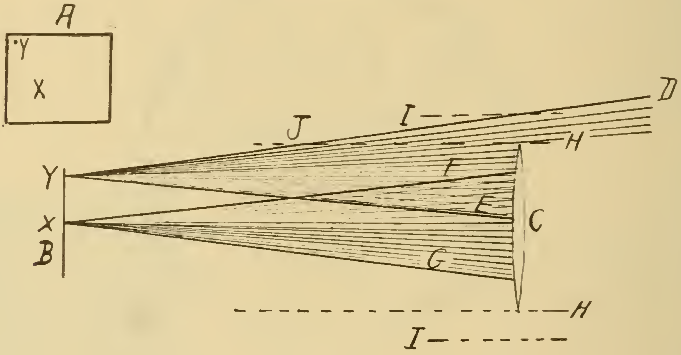


FIGURE 87

Observe that in the center zone the light intensity is 24.3 foot candles. Because the total area of the zone is very small, the light flux therein represents only 10.8 percent of the total, regardless of the fact that the small zone is very brilliant.

Examining zone 2 we see that the light intensity drops to about 13.6 foot candles, but nevertheless, because of the larger area, zone 2 supplies almost five times the total light—49.2 percent more than zone 1, —while zone 3, which drops down to 5.9 foot candles, supplies 40 percent of the total illumination.

A very interesting point here is that whereas these are the measurements when the converging lens is 18 inches from the aperture and the projection lens at a 3 inch working distance, when the converger is the same distance from the aperture, but the projection lens at

7 inch working distance, the zone readings average: center 13 c. p., zone two 10.1, while zone 3 holds up to 5.6, which is almost its value under the other condition.

Failure to get the entire light beam into the projection lens means very real loss of light. Long focal length lenses generally provide more even screen illumination than the shorter focal length ones.

In Fig. 85 we see a normal light beam from a 2-lens plano-convex condenser. Note the circle of light on the back of the aperture plate. It is caused by light reflected from surfaces of various elements of the projection lens, each of which adds its quota. When the picture was made the lenses were very clean. Had they been fogged with dust or dirt, reflection loss would have been increased in proportion to the amount of fogging.

PROJECTOR OPTICAL TRAIN

(114) The projector optical train consists of two entirely separate elements joined together more or less efficiently. Efficiency of the jointure depends upon the amount of skill with which it is made.

(115) First, the condenser or mirror which collects light from the light source, bends or reflects its diverging rays and concentrates it upon the cooling plate and aperture of the projector mechanism. Second, (116) the projection lens, which receives the rays passing through the film photograph and focuses all their millions of numbers upon their appointed spot in the screen image.

Light leaves the light source in diverging rays (Figs. 75 and 83), which move forward until the face of the collector lens or curved mirror is reached. (117) The light source and collector should be as close together as possible.

(118) Examining Fig. 88, the reason for minimum distance becomes self-evident. We see that it would require a collector 7.25 inches in diameter located 4.5 inches from the light source to collect the same amount of light available to a collector 4.25 inches in diameter but only 2.5 inches from the light source.

It is thus evident that any unnecessary distance between light source and collector involves heavy light loss.

LIMITATIONS GOVERNING DISTANCE

(119) Limitations vary with the character of the light source. With filament it is almost wholly optical, the only other limiting factor being the diameter of the globe of the lamp, which itself prevents the light source (filament) from being advanced nearer to the collector lens by more than half the diameter of the globe.

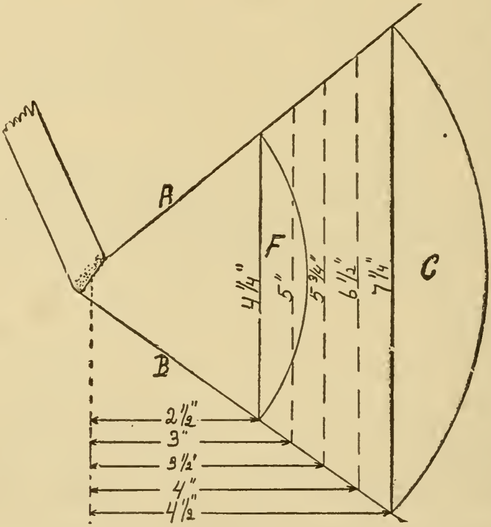


FIGURE 88

The optic requirements for the distance from the light source to the collector demand the beam of light to spread sufficiently to form a "spot" of sufficient diameter at the required distance from the converging lens to the projector aperture. As the light source is brought nearer the collector lens of a condenser, or the surface of a curved mirror, such as is used in projection, the light beam on the opposite side of the condenser or in front of the mirror or condenser converging lens is increased in diameter.

Where the light source is an electric arc, the two limiting factors of distance are (a) enough distance to set up the required beam diameter at the projector aperture, and (b) heat. Heat is the main governing factor where high power electric arcs are used; often a more satisfactory optical condition might be had with the collector closer to the light source but heat will not permit it.

(120) Condenser lenses have a thin edge and a thick center and consequently they heat and expand much more rapidly at their outer zones than at their center, which sets up a condition of great strain, (121) particularly if the light source is a powerful one, or has a heavy tail flame. A heavy tail flame creates an extremely high temperature at one point—the upper edge of the collector lens—and cracks the lens if the distance of the light source to the lens is too short. (122) This may be controlled somewhat by interposing a small sheet of mica between the outer portion of the flame and lens, but the mica must be out of range of the light cone incident upon the lens.

The distance of the light source to the lens may be increased by installing a converging lens (a plano-convex condenser) of longer focal length. This cannot be done with a parabolic combination. (123) The plano-convex condenser collector lens should always be 6.5-inch focal length. The converger should have a focal length sufficient to set up the proper condition at the aperture when the light source is at the minimum permissible distance from the collector.

Lens Pitting

(124) Pitting is caused by particles of incandescent matter from the light source striking the lens and ruining the polish at point of impact. As a consequence the light that strikes a pitted spot is diffused and very largely wasted. Pitting may be decreased or stopped altogether by lengthening the distance from the light source to the lens, but that entails heavy loss of light (see Fig. 88) and the "gain" is likely to prove a loss. With increased distance the lens will not have to be

renewed so often, but current bills will be bigger—or as an alternative screen illumination will be decreased.

THE COLLECTOR

We now arrive at the collector, which may be either a glass lens or a curved mirror. (125) If it is a lens (a plano convex condenser) it should be a 6.5-inch focal length lens, (126) with the focal length of the converging lens sufficient to provide the necessary spot diameter at the aperture and a minimum distance from the light source to the collector. This applies only to the plano-convex 2-lens condenser. (127) The lenses are placed with their curved surfaces together for two reasons. First, were the collector lens placed with its curved surface toward the light source, the reflection from its outer zones would be very high—in fact, if the distance from the light source to the lens is short, the reflection at its outer zones would include almost all the light incident on these zones. Second, with its curved surfaces together, opticians tell us there is less spherical aberration than when mounted the other way.

SPACING CONDENSER LENSES

(128) Condenser lenses should be as close together as possible without actual physical contact. Contact would transfer heat from the very hot collector to a single spot on the relatively cool converging lens. (129) As Fig. 89 shows, the collector does not send forward a parallel, but a diverging beam. The actual separation need be no more than 1/64 inch but it must be enough to prevent actual physical contact.

THE CONVERGING LENS

With a 2-lens plano-convex condenser, use a 6.5-inch focal length collector in conjunction with a converging lens of sufficient focal length to give the required spot diameter at the desired distance. (130) The spot diameter will be dependent upon the focal length of the combination, when the distance from the converging lens to aperture has been fixed.

(131) Ascertain the minimum possible distance the light source may be carried from the collector lens or the mirror and the minimum spot diameter that may be maintained without discoloration of the screen illumination. Select a condenser that will establish these conditions.

THE MIRROR COLLECTOR-CONVERGER

(132) Mirrors are used to collect light either to project it in a parallel beam back to a large-diameter, thin condensing lens, which in turn converges the light to a spot at the projector aperture, or to collect the light and reflect it directly back in a converging beam to the projector aperture. They are available in three forms: spherical, parabolic and elliptical. In Fig. 90 the nature of the three surfaces is indicated in exaggerated form.

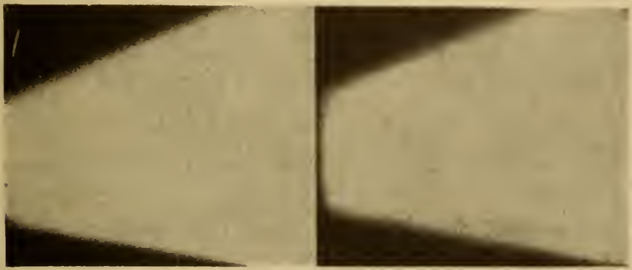


FIG. 89.—Beams from 6.50 inch and 7.50 inch focal length lenses.

(133) In Fig. 81 we saw that in an uncorrected lens the quality termed "spherical aberration" causes the rays from a light source of considerable area that are incident upon the outer zones of the lens, to focus closer to the lens than those incident upon its more central zones. This effect becomes progressively greater from the optical axis of the lens outward. (134) All spherical mirrors have this fault (135) which may be corrected by a very slight departure from the true spherical curve along the lines shown at A and B in Fig. 90. (136) It is this departure that constitutes the parabolic and the elliptical mirror.

Knowing that the angle at which a light ray meets a reflecting surface (angle of incidence) is always equal to the angle at which it is reflected therefrom (angle of reflection), it will be understood readily that if the surface of the mirror or a lens is accurately curved along the lines indicated by curves A and B in Fig. 90, the rays from the outer zones will spread sufficiently to focus at the same plane as those from the central zones. Thus spherical aberration will be "corrected."

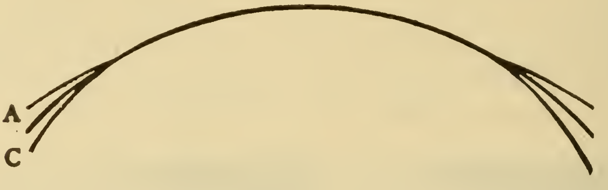


Fig. 90.—The elliptical and parabolic curves are exaggerated. In actual practice they are invisible to the eye. A is parabolic; B is elliptical; C is spherical.

(137) In practice spherical aberration forces rays that normally should pass through the aperture to fall wastefully upon the cooling plate and forces other rays that pass through the aperture to fall either entirely outside the lens, or upon the wrong spot on the lens.

(138) On the other hand it is true that spherical aberration breaks up the light source image, causing its high and low points of illumination to merge together. Today, since only the light from one high intensity carbon requires breaking up, spherical aberration may be considered a harmful characteristic in a lens.

(139) If properly installed and adjusted, a mirror will collect a much wider angle of light per unit of electrical energy (calculated at the light source) than a 4.25 inch free diameter condenser collector lens is able to do, and for the following reason:

Fig. 91 shows the face of a 4.25-inch free diameter plano-convex collector lens. Observe that when the light source is located 3 inches away it is able to collect but a 70 degree angle of light. The rest falls outside the lens. Here degrees represent a section or arc of a circle, the center of which is, at the light source, a curve representing the circumference passing through both edges of the lens. The 70 degrees do not represent the total light picked up since in the case of either lens or mirror the strongest light goes straight out from the face of the crater floor.

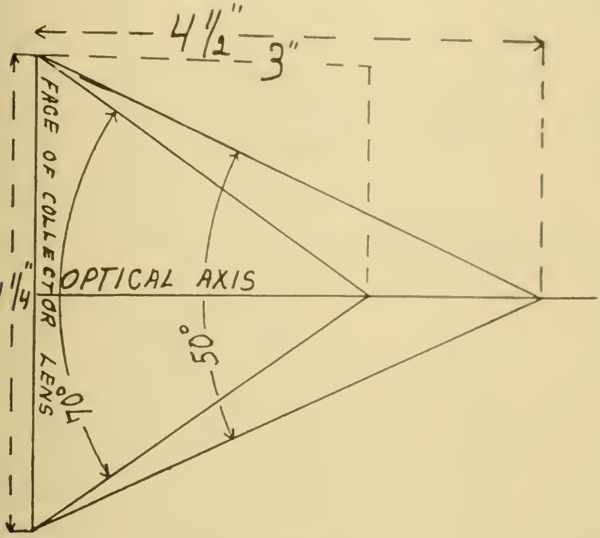


Figure 91

Were the lens located 4.5 inches from the light source it would intercept but a 50 degree angle of light, the two distances representing the minimum and maximum distances from the light source to the lens or mirror.

(140) Turning next to Fig. 92, we view a mirror collector 7.5 inches in diameter, the light source located 3.3 inches from its vertex (center). It will intercept an angle of light of 120 degrees. If we increase the mirror diameter to 8 inches and locate the light source 4.5 inches from the mirror vertex, it will still intercept a 100 degree angle of light, as against the smaller angle available to the 4.25 inch free diameter glass collector under analogous conditions. Even if we use a 6⅝ inch diameter mirror, with light source 3.75 inches from its vertex, we can collect approximately a 95 degree light angle.

(141) From all this it is evident the mirror is a far more efficient collector of light than the 4.25 inch free diameter 2-lens plano-convex condenser. This is by no means its only advantage. Most of the reflector type lamps use no condenser at all, the mirror reflecting the collected light directly back and converging it into the "spot" at the cooling plate-aperture. It eliminates the very heavy light loss due to reflection from the four glass surfaces encountered in 2-lens condensers, in addition to the loss sustained in the absorption of light by the glass itself.

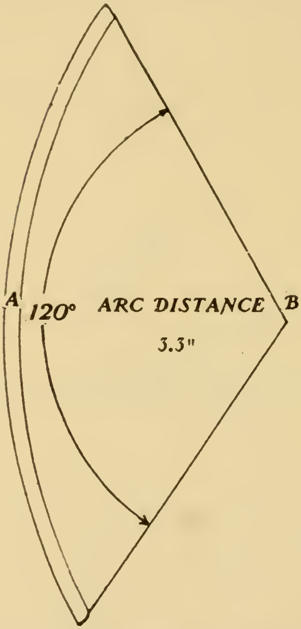


Fig. 92.—Showing mirror diameter 7.5 inches parabolic curve.

As against this high efficiency in light collection and delivery at the projector aperture, the lens in the reflector type lamp, using a thin condenser, wastes (mostly by reflection) about 12 percent of the rays, and the mirror itself wastes (again largely by reflection at the glass surface) about 8 percent; the remainder is sent forward to the cooling plate and aperture.

The loss on account of reflection will increase if the lens surface is not kept perfectly clean.

(142) The mirror loses less light through absorption but it creates a very hot spot at the aperture, there being no condenser to absorb any portion of the heat rays. Whenever a condenser is used, thin and of wide diameter, the aperture heat is somewhat reduced because the lens absorbs and radiates a considerable portion of it.

(143) When the rotating shutter was located on the screen side of the projection lens it in no wise reduced the spot heat produced by reflector type equipment. But

when it was shifted to a position between the light source and the aperture it cut the heat down approximately 50 percent. The mirror hot spot, therefore, is no longer an important point. Rear shutters create a strong current of air which has a very decided cooling effect at the aperture.

(144) In choosing between the mirror collector and the 2-lens glass condenser remember that the mirror, of the two, is the more efficient collector of light. It is slightly deficient because of its high aperture temperature but it is still to be preferred except where a straight high arc is used which must have a 2-lens glass condenser.

Mirror Action

We will now try to make clear the action of curved mirrors used in high and low intensity reflector type

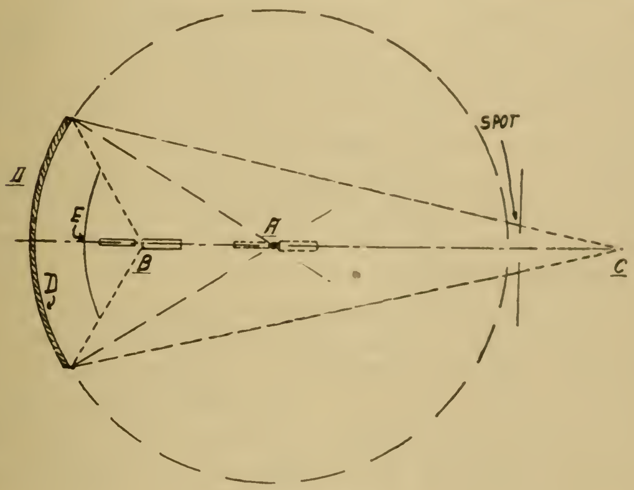


Figure 93

lamps. Fig. 93 shows a curved mirror and projector aperture, with the light source AB in two positions. The mirror being spherical, its curvature corresponds exactly to that of the broken line curve, the center of which is at A.

(145) Now if light source A were a point (having

no area), all rays reflected by the mirror surface would focus at point C. But a light source is not a point; it has considerable area. Therefore rays from its outer margins meet the mirror surface at a slightly different angle than those coming from its center. This has the effect of producing what we call "spherical aberration," since the difference of angle of incidence will cause rays striking the outer zones of the collector to focus closer than the rays from the central zones. If you lay the lines out on paper you will see that while the rays from the outer margins of the light source to the center of the mirror or lens will be affected, still the rays to the outer zones of the collector will be affected very much more. It is wholly a matter of the angles at which rays from the light source meet the different zones of the mirror surface.

The angle of incidence is always exactly equal to the angle of reflection. In a spherical mirror all points of the surface cannot correspond precisely at the same angle to points on a light source and therefore the rays reflected by the different zones of the mirror will focus at different distances from its reflecting surface.

(146) This condition causes spherical aberration. It can be corrected, partly, by tilting the outer zones of the mirror slightly backward which gives either a parabolic or an elliptical effect. •

(147) It is evident that if light source A, in Fig. 93, was moved closer to the mirror, to B, the angles of incidence and reflection would be so altered that the beam would no longer focus at C, but much further back. It is this action that explains the reduction or enlargement of the spot diameter as the light source is moved nearer to or further away from the mirror.

Selection of Mirror Collector

(148) Silver has the highest power of reflection, and polished glass the smoothest, closest grain surface of any substances suitable for mirrors. Therefore they yield the highest possible accuracy and optical efficiency in any product designed for the reflection of light.

(149) Silver will tarnish when exposed to air. To overcome this tendency it is placed upon the polished back of a curved glass mirror and (150) upon it is laid a coat of a heat resisting, non-porous covering called "mirror backing." The glass itself, of course, protects the silver on the other side.

In mirror reflectors of the parabolic or elliptical type (151) the light source must be located at a certain fixed distance from the mirror surface, and the mirror surface in its turn a certain fixed distance from the projector aperture. Any departure from these distances, particularly of the distance from the light source to the mirror, will mean loss in efficiency. (152) The distance from the light source to the mirror vertex is called the "mirror focus." (153) The distance from mirror vertex to the aperture is called the "mirror working distance."

(154) For best results mirrors must be operated at exactly the correct focus and working distance. (155) Distances are not the same for mirrors of different focal lengths. (156) An error of less than one millimeter in mirror focus distance is a very serious matter. It is therefore well to proceed with great caution in making changes in the adjustments of the mirror, especially when changing mirror focal lengths. Where slight alterations may produce such serious results it is a much better plan to follow the manufacturer's recommendations and instructions very carefully, varying from them only when you are positively certain that results will be improved. You can secure instruction books freely by writing to the manufacturers.

(157) For low intensity lamps, it is advisable to use mirrors made of high grade optical glass which will not crack readily from heat if correct distances are maintained. When using the reflector type high intensity lamps, however, the mirror must be of high grade, heat resisting glass (pyrex, for example), if excessive breakage is to be avoided.

CARE OF MIRRORS

(158) Mirrors cannot function efficiently unless the

silver reflecting surfaces remain whole and untarnished and the front (glass) surfaces are always clean and undamaged. (159) Low intensity lamp mirrors should be wiped clean and polished with a clean, soft cloth at least once each day, and not less than twice each day where performances are continuous.

(160) In the morning, when the mirror is cold, polish it thoroughly with a clean, soft cloth. An excellent cleaning fluid is pure grain alcohol and clean water, mixed half and half. Dampen a cloth with it, wipe the mirror face and polish quickly and thoroughly. Do not use denatured alcohol as it contains chemicals that leave a thin film on the glass.

(161) Where the flaming type high intensity is used the mirror surface should be wiped with a bit of cloth wet with the water-alcohol mixture, and polished thoroughly, using only a clean, dry, soft cloth. Afterward wipe its surface with a clean, soft cloth immediately before striking the arc for each run. This also holds true for the a. c. arc.

(162) Once each week and daily in continuous theatres, regardless of whether you have high or low intensity, remove the mirrors and wash them thoroughly with strong soapsuds. Rinse the soap off and polish them with a soft, clean cloth or soft tissue paper. Some projectionists do this every morning, which is a good practice. Do not get the back of the mirror wet.

Tarnished Mirrors

(163) Under the action of heat, the silver reflection surface will tarnish in time. When this occurs the mirror should be returned immediately to the manufacturer, either directly or through your dealer, for resilvering. (164) If the mirror is pitted or scratched, and the marks are not too deep, the mirror can be ground off and made as good as new at less than the cost of a new one. But if the pit marks or scratches are deep, regrinding is too costly and the mirror should be replaced.

(165) Do not continue a badly scratched or pitted

mirror in service. If you do you will waste more light (power) than a new mirror is worth.

TREATED LENS SURFACES

(166) As noted in Paragraph 69 of the present chapter, any lens wastes a certain amount of light by reflection at air-to-glass or glass-to-air surfaces. Since there are many such surfaces in the compound lenses used for projection, the loss of light in common types of projection lenses may mount up to as much as 33⅓rd percent, according to expert authority.

(167) An ordinary window pane is not a mirror and is not meant to be; most of the light that strikes it passes right through it, and thus the sheet of glass is by and large transparent; nevertheless everyone has seen his reflection in an ordinary window pane in virtue of the fact that the glass is not 100 per cent transparent but reflects some portion of light from its air-and-glass surfaces. When the projection lens wastes light by reflecting some of it, instead of transmitting it all, it is only doing what all glass does.

(168) This loss of light by reflection is important in the theatre. In cases where it amounts to as much as 33⅓rd per cent, one out of every three dollars paid for current to provide the projection light is wasted. Additionally, lens reflection impairs the contrast of light and shadow on the motion picture screen, because a goodly portion of the reflected light does get to the screen eventually, by reflection from the surface of the motion picture film or from other surfaces of the compound lens; but it arrives at the screen entirely out of focus, not having gone through the lens in the intended manner; and thus it acts to spread a diffuse, scattered illumination over the entire screen area, dimming the sharpness of the picture. In the projection of color pictures, this diffused light resulting from lens reflections casts a many-tinted haze that dulls the sharpness and clarity of the colors.

(169) About fifty years ago photographers and optical workers noticed that a tarnished lens *sometimes* lost

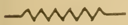
less light by reflection than a clean one. It did not happen often, and the effect could not be reproduced by intentionally soiling the lens; but it did happen once in a while. Investigation in recent years has proved that the effect could be reproduced accurately by carefully controlling the *thickness* (or rather, the thinness) of the layer of tarnish on glass-to-air surfaces.

(170) Lenses made today are intentionally "treated" or "surfaced" at the factory to reduce their reflection losses. Sub-microscopically thin layers or films are produced on the glass by chemical action. The thickness of these deposits is governed by careful control of the concentration of the chemicals used and of the length of time the glass is exposed to their action.

(171) Lenses purchased before the treating process came into use can be surface-treated either by the maker or by companies engaged in that business.

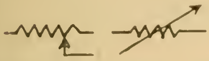
(172) Surface treatment, it is authoritatively stated, can reduce reflection losses in projection lenses by ⅔rds. On this basis, where an untreated lens wasted $1 out of every $3 spent for electricity to provide projection light, the same lens wastes only 33c out of $3 after it is "treated." And there is a corresponding gain in the sharpness of the image, and in the clearness of color pictures, through the reduction of ⅔rds in the amount of diffused light reaching the screen as a result of lens reflections.

(173) Treated lenses impose one important precaution on the projectionist. He must be very careful to clean them *only* as recommended by the manufacturer or by the company that applied the treatment. More than one type of treatment is known today, and the different coatings produced may be damaged by one or another method of cleaning. The projectionist should take the trouble to inquire into the correct method of cleaning *his* coated lenses, and adhere to it scrupulously. A projectionist taking over a new assignment, whether temporarily or permanently, must be careful to inquire, before attempting to clean the lenses, whether or not they are treated, and if so, what cleaning method is recommended for the particular treatment applied.



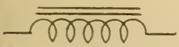
Resistance

Fig. 94



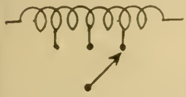
Variable Resistance

Fig. 95



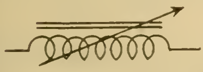
Inductance

Fig. 96



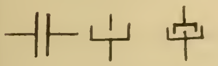
Variable Inductance

Fig. 97



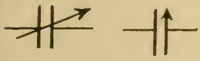
Variable Inductance

Fig. 98



Condenser

Fig. 99



Variable Condenser

Fig. 100

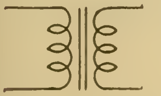


Fig. 100A
Air core Transformer

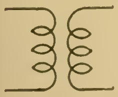
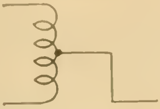
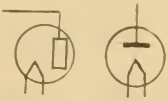


Fig. 101B
Iron core Transformer



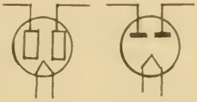
Auto-Transformer

Fig. 102



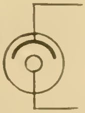
Diode for half wave rectifier

Fig. 103



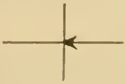
Diode for full wave Rectifier

Fig. 104



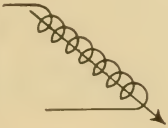
Photoelectric Cell

Fig. 105



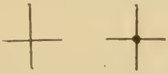
Dry Chemical (stack) rectifier arrow side positive

Fig. 106



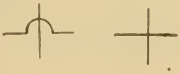
Phonograph Pick-Up (Reproducer)

Fig. 107



Wires touch

Fig. 108



Wires, crossed, not joined

Fig. 109

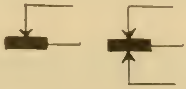


Fig. 110
Carbon Microphone

Symbols Used in Electrical Drawings

SCREENS

Practical Questions

(For answer to each question see statement of corresponding number in Chapter X)

1. What are the items of basic importance in a screen?
2. What does wasted light represent?
3. What two chief items are involved in consideration of reflection power?
4. Is the amount of light reflected in one direction necessarily any indication of the amount reflected in other directions?
5. What affects reflection power?
6. Do all pure white surfaces have equal reflection power?
7. Why is loosely woven white cloth a poor reflection surface?
8. How may fine, hard-twist white cloth be made a good reflection surface?
9. What white pigment recently developed is considered the equal or superior of white lead and white zinc?
10. Name still another white pigment in common use.
11. Can pigments be used alone?
12. Name the chief points for and against glass bead screens.
13. Can a glass bead screen be cleaned to restore its reflection powers in full?
14. For what condition is the glass bead screen or other specular surface best suited; for what conditions ill suited?
15. Is reflection power of all screens reduced at each cleaning?
16. Upon what points should exhibitors and projectionsist concentrate when purchasing a new screen?
17. Is the percentage of reflected light a varying element?
18. What causes variation?

TESTING REFLECTION POWER, PAGE 228

19. How may loss in reflection power due to age or accumulation of dirt be tested in a thoroughly practical manner?
20. Are statements that a screen will reflect light in excess of 110 percent correct?

21. What does Table No. 3 show?
22. Should exhibitors accept unsupported statements regarding the reflection power of certain substances?
23. What is the relative reflection power of certain substances?
24. How would you analyze Table No. 3?
25. What screen attribute is more important than the amount of light reflected?

LIGHT TONE, PAGE 232

26. May the tone or color of light be affected by a screen surface without tinting the surface?
27. What kind of screen surface should be selected when a filament-type projection light source is used?
28. What is the problem when a high power arc light source is used?

TYPE OF SURFACE, SIDE ANGLE DISTORTION, PAGE 232

29. What is the difference between a "specular" and a "diffusing" screen?
30. What decides which type of screen surface is needed in your theatre?
31. What knowledge is useful in the selection of a proper screen for a particular theatre? How may such knowledge be obtained?
32. Why will those seated at a "heavy" side angle to the screen see objects at less than their true width and seemingly abnormally tall?
33. What is the one possible remedy for this condition?
34. What screen is best where "heavy" viewing angles are involved?

SCREEN MOUNTING, PAGE 234

35. What is the best screen mount?

CLEANING SCREENS, PAGE 235

36. Is it true that any screen surface can be cleaned to restore 100 percent of its reflection value?

37. Do all screen surfaces except glass undergo chemical changes?
38. Should a guarantee accompany each new screen, covering the feasibility and cost of recoating its surface?

PERFORATIONS, PAGE 235

39. Approximately how many perforations are there to each square foot of an average perforated screen?
40. How much reflection surface and picture detail is eliminated by perforation?
41. Is there any valid reason for the use of perforated screens?

HOW TO OBTAIN VIEWING ANGLES, PAGE 236

42. How may viewing angles be calculated?
43. What maintenance difficulties do perforated screens present?
44. What objections are there to too much or too little distance from seats to screen?
45. What should be the minimum distance from front seats to the screen?
46. How high should the picture be above the floor?

PICTURE SIZE AND LIGHT DEMAND, PAGE 238

47. What point is immediately involved when the size of the picture is under consideration?
48. What effect has picture size on illumination?
49. What effect has picture size upon magnification?
50. How may magnification be calculated?
51. What effect has bigger picture size upon visibility of defects in photography?
52. What relation is there between the size of the picture and the brilliancy of illumination?
53. What relation is there between the size of the picture and its surroundings?

54. Except under unusual conditions what maximum picture size is best?

TINTING, PAGE 240

55. Has screen tinting any real value? Are there valid objections to it?

LOCATION AND SURROUNDINGS OF SCREEN, PAGE 240

56. What should be the position of screen on stage?
57. What should be done to the stage floor in front of the screen?
58. What is important with regard to the immediate surroundings of the screen?
59. What constitutes the best screen border?
60. Are theatre screens ever evenly illuminated over their entire area?
61. What precaution should be observed when preparing to purchase and install a new screen?
62. Will a home-made screen give results as good as those obtainable from a scientifically constructed reflecting surface?
63. What is the best base for a home-made screen?
64. Describe the construction of a screen base and of a suitable frame for mounting the same.
65. Describe the preparation of a preliminary coating for first treatment of a muslin screen.
66. What materials should be selected for mixing screen paint, and how should each coat be applied?
67. Can a perforated screen be recoated by the exhibitor?
68. What must be avoided in recoating perforated screens?
69. What test should be made before starting to paint an old screen surface?
70. If the paint will not adhere to surface what should be done?
71. By what means is it possible to free the perforations of surplus paint or kalsomine?
72. What is the best method of applying paint or kalsomine to a screen?
73. What screen image sizes have been suggested by the S.M.P.E.?

74. What should be the level of illumination in theatre auditoriums?
75. What is the effect of light other than that from the projection lens falling upon the screen?
76. Should any light other than that from the lens be permitted to reach the screen?
77. What is a "glare spot"?
78. How may viewing comfort be increased from any distance?

CHAPTER X

SCREENS

(1) From the audience point of view the function of a screen is to reflect the projected picture in the most pleasing manner. Technically this calls for a number of things: (a) It must deliver to the audience the largest possible percentage of the light incident upon its surface; (b) it must do this with a minimum fadeaway at side angles and (c) it must oppose a minimum interference to sound volume and distribution.

These are characteristics that should be required when purchasing a new screen to assure a full measure of efficiency during its life in the theatre.

Reflecting Surfaces

(2) The efficiency of the screen in reflecting light is of great importance. If it fails, either the beauty of the picture will be damaged or increased electrical power (light) will be required to give the picture full screen values. This greater power consumption will soon assume sizable proportions in the theatre's overhead expenses.

(3) In selecting a screen, bear in mind two distinct factors—one, the total percentage of incident light reflected and two, its distribution. (4) Measurement in a single direction is no proof of the total reflection power of a surface. A screen surface that has high efficiency in a 25-foot wide auditorium might be extremely inefficient in one 50 feet wide.

(5) Reflection power is affected by (a) character of surface, (b) color, (c) cleanliness, and (d) its age. The surface reflecting the greatest percentage of incident light, other things being equal, is pure white. (6) How-

ever, not all pure white surfaces have equal reflection power. There is density and character of the surface to consider.

(7) Loosely woven, untreated white cloth, for example, while it may be pure white, is nevertheless a very poor reflecting surface for the double reason that it permits a considerable percentage of the light to pass through, and because much light is absorbed by the fabric itself, into which it enters but does not pass through.

White cloth made of fine, hard-twist, closely woven thread is a good reflecting surface, (8) provided its back is properly treated with a pure white coating such as kalsomine, or white lead and white zinc (50-50 mixture) paint.

(9) Titanium dioxide is a white pigment that can be called recent in comparison with white lead, for example, which has been known for centuries. It is considered one of the best white pigments known today.

(10) Another very white substance and one that is widely and successfully used, is lithopone. This is a mixture of approximately 30 per cent zinc sulphide and approximately 70 per cent barium sulphate.

(11) None of these pigments can be used alone for the reason that they are all fine powders. For practical use they must be mixed with some binding material, which may be either a drying oil or a plastic like the material of motion picture film. Loss of a screen's reflective power is more likely to be the result of aging of the binding material than of aging of the pigment.

(12) Glass bead screens have high frontal reflection powers and very low powers of diffusion. They may be cleaned better than other surfaces, but (13) their original reflection power cannot be restored, because the binder material in which the beads are embedded is a part of the screen's reflecting surface and discolors with time.

(14) Glass bead screens are not suited for wide auditoriums or for theatres with balconies or steep projection angles. Bead screens are better suited for use in

long, narrow auditoriums where the projection angle is moderate and the balcony, if any, is low. Under such conditions they are highly efficient.

REFLECTION POWER AND AGE OF SCREEN

There are many different types of screen surface, some of which have excellent and some comparatively poor powers of reflection and diffusion. (15) The reflection powers of most screens are good when new, but some of them deteriorate quite rapidly. It is impossible to restore any screen to its original value through cleaning. Moreover, reflection power is lessened with each cleaning. Taking these facts into consideration, it is evident that both projectionists and exhibitors should study screen surface characteristics very carefully, basing such study upon (16) (a) reflection power when new and (b) rapidity with which various surfaces will discolor, or absorb and accumulate dirt, (c) probable percentage of original reflection power that may be restored by cleaning, (d) cost of refinishing the surface and (e) angles at which light will be reflected. It is important to select a screen surface that will most efficiently serve the seating space of the auditorium.

(17) The percentage of incident light reflected is a highly variable item. What percentage of light a screen surface will reflect when new and what it will reflect after six months' use are widely divergent facts. (18) Reflection power varies with the character of the surface. Exposure to air has a decided effect and so has the location of the theatre because in some sections the air is laden with impurities which settle on the screen surface.

It is therefore impossible to gauge exactly the loss of reflection power over a period of time. For example, in Buena Vista, Colorado, deterioration would be relatively slow because the mountain air is very pure and clean. In industrial centers, on the other hand, the air is filled with carbon dust and other impurities and screens lose reflection power quite rapidly.

TESTING REFLECTION POWER

(19) At the time of purchasing the screen insist upon an extra sample of not less than six inches wide by six feet long. A piece 18 inches square will serve equally well. Wrap this sample in at least two thicknesses of soft black cloth. Lay it away on the shelf of some dark closet where it will remain dry. Cared for thus, it will undergo little or no change for a long time unless its surface contains chemicals that discolor without exposure to light. To test the screen surface, suspend the sample, by means of small wire hooks as nearly as practicable in the center of the screen. Project a reel of pictures and observe the effect. A sheet of white, rough-finish cardboard will serve in place of the screen sample if that is not available. White blotting paper may also be used. Paper is not always satisfactory because its properties are not identical with the screen but it will give a fairly good idea of the condition of the surface. The white paper test is valueless against a tinted screen surface.

It is better to make the test with a reel of pictures rather than with the light alone because actual working conditions yield a better comparison.

(20) No object or substance known to man reflects all the light striking its entire surface. There is always some loss. It cannot be truthfully said that the reflection power of any screen surface is in excess of 100 percent. It is always less than 100 percent.

However, some surfaces show more than 100 percent reflection power through a comparatively narrow angle, which only means that the other angles have been robbed of a portion of their light. (21) The situation is shown in the accompanying tabulation. Surface F, for example, shows 132 percent at 0 degrees angle, but at a 50 degree angle it sinks to 37 percent. The angles from 20 degrees up have been robbed of light to make the space within 20 degrees very brilliant. While the amount of total light reflected by a screen is important, it is not so important as the directions in which it is reflected.

(22) Despite statements made by screen salesmen, photometric measurements of reflected light can be made. For the convenience of Bluebook readers the engineering department of the Eastman Kodak Company made a series of test measurements of the reflection and diffusion powers of certain well known surfaces which are tabulated below.

(23) In the accompanying tabulation each surface is given a designating letter, as follows: A—Magnesium, a chalk-like substance the reflection power of which was taken as a standard because of its high reflection value and uniform distribution powers. Its 0 degree angle of reflection power was arbitrarily assumed to be 100 for purposes of comparison with other surfaces. B—Fine grade cotton sheeting. C—Two coats of white paint on cardboard. D—Smooth calendered cardboard. E—Kalsomine on plastered wall. F—Wallboard painted two coats of aluminum paint.

TABLE 3

(Angles of light measuring instrument to screen surface when measurements were made.)

Surface	0 deg.	5 deg.	10 deg.	20 deg.	30 deg.	40 deg.	50 deg.	Average
A	100	100	60	98	80	76	97	99
B	61	61	82	59	74	83	56	59
C	80	79	99	77	57	58	70	76
D	113	109	78	94	98	98	79	95
E	82	82	106	81	81	81	81	81.5
F	132	125	115	88	66	50	37	73

The column of averages was arrived at by adding the reflections at all measured angles together and dividing by seven, the number of angles, which is only approximately correct but serves our purpose.

The variations are entirely due to differences in reflection characteristics of the various surfaces and difference in direction in which the light is reflected.

(24) Evidently surface A gives a good and very even screen brilliancy to people seated in all parts of a wide theatre auditorium, since the light is evenly reflected in all directions. There is no visible fadeaway. This sur-

face, however, is not available for theatre screens. B provides excellent power of light diffusion, but is relatively low in reflecting power. Surfaces D and F concentrate a large proportion of the total light at the center of the auditorium. The picture would be very bright from straight in front of the screen, but quite dim at wide viewing angles. The total reflection power is

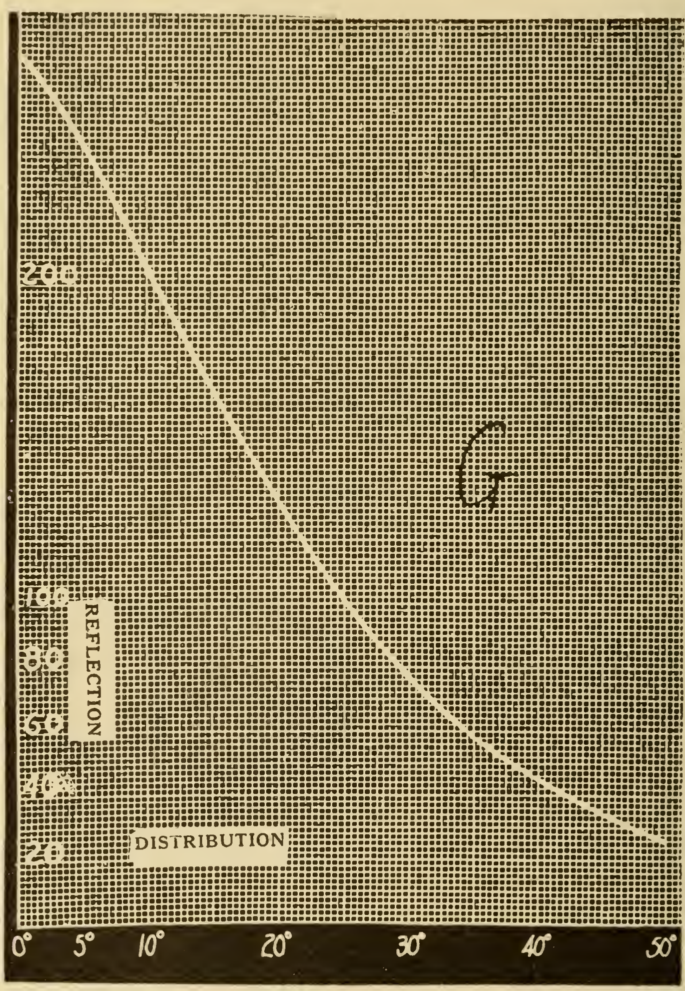


Figure 111

high, but the distribution is very poor. They are obviously suited only for use in long, narrow auditoriums. Of the surfaces measured, C and E best serve wide theatres. Surface B is still better for light distribution but quite low in reflecting power.

Fig. 111 sets forth ratios of distribution of reflection power. Observe that vertically at the left are figures from 0 to 300 which represent reflection power of the surface. The extreme left edge is the line representing the reflection power of the surface when viewed from straight in front of the center of the surface—in line with the axis of projection. There the reflection power reaches to 270, one hundred representing its brightness where the light is evenly distributed. This added brilliancy is taken from the margins, which drop, you will observe, very low.

At the bottom are figures representing angles of view, or "viewing angles." The slightly curving white line represents the reflection power of the surface at every possible viewing angle up to 50 degrees. If you follow the vertical line immediately over 25 until it meets the white line, it does so at the horizontal line extending to the left of 100. This means that if the screen is viewed at an angle of 25 degrees it will only be as bright, compared with brightness when viewed from straight in front, as 100 is to about 270, while at a 50 degree viewing angle the illumination will drop until the brightness, as compared with a straight front viewing angle, will be only in the ratio of 26 to 270. This indicates the condition known as "fadeaway."

Fig. 111 and table No. 3 shows the necessity of careful investigation of reflecting and distributing powers of surfaces before installing a screen. Projectionists and theatre managers should require the manufacturer to supply such measurements and to check through with an expert testing organization.

(25) A study of the foregoing tabulation makes it evident that, important as reflection power is, the distribution of light is of even greater concern.

LIGHT TONE

(26) Color, shade or tone of reflected light may be influenced to some extent by the character of the screen surface but without appreciably decreasing its power of reflection. Some theatres, employing the same light source, vary among themselves in the character of their screen illumination. Some have a sharp, harsh light; in others it is mild and pleasing. This may be due to factors other than the screen or it may be due to differences in the screen surfaces, though not necessarily to differences in surface tinting.

(27) Theatres using a filament projection light source should install the most brilliant screen surface purchasable, paying due attention to the diffusion of light necessary to their auditoriums. Light source in such theatres would be limited in power and of a pale amber tint, as compared with an arc light. The problem, therefore, is not to reduce harshness, but to procure a screen surface that will reflect the highest possible light reflection characteristics.

(28) On the other hand, theatres using high power, high intensity arc lamps, which provide the maximum amount of projection light, but of a more or less harsh tone, should have a screen surface of less brilliant white in order to reduce the harshness. This is another problem that deserves consideration by the exhibitor and projectionist.

TYPE OF SURFACE—SIDE ANGLE DISTORTION

(29) As previously indicated, some reflecting surfaces will distribute or diffuse light evenly all over a wide auditorium while others will not, concentrating a large percentage within a relatively narrow angle. The first are diffusing, the second specular surfaces, and between these extremes are many different grades.

(30) Which surface will give uniformly best results in any specific auditorium will depend upon the width of the seating space near the forward end, height of balcony above main floor, and the nearness of front seats to the screen.

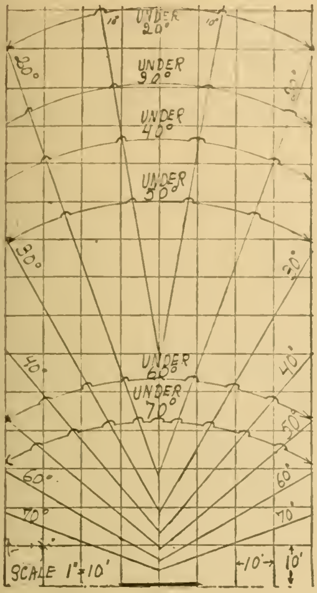


FIG. 112.—A straight edge laid on any of the lines will touch the side of the screen opposite.

(31) To know what kind of screen surface is best for your theatre you must know all the viewing angles. This may be ascertained by following Fig. 112, which is laid out in squares. Measure the inside dimensions of your auditorium. Each one of the vertical lines represents a ten-foot width. Each horizontal line represents ten feet of depth. If your auditorium measures 40 feet wide by 70 feet deep, you have only to count back from the screen to the seventh horizontal line in Fig. 112. Then count to the second vertical line on each side of the center line and you have your theatre floor plan laid out in the diagram.

Suppose your seating takes in the full width of the theatre—no side aisles—and that it comes within 15 feet of the screen and within 8 feet of the rear wall. That calls for a screen of high diffusing power, since a considerable number of seats will be beyond the 40 degree angle, many outside the 50 degree angle and a few even outside the 60 degree angle. It's a bad condition for two reasons: first, the best available screen surface cannot distribute light over so wide an angle without perceptible fadeaway, and secondly, it creates heavy visual distortion from the front side seats.

(32) Those seated at a heavy horizontal angle to the screen surface see all objects thereon as abnormally tall and thin. When an object we always see in certain proportions of width and height is suddenly reduced in width, it then appears to be taller than it really is.

Examining Fig. 113 we see an object of a certain width on the screen represented by A-B. An observer seated at C will see this object in its normal width, but an observer at D will not. He will instead see it as of B-G width. This effect is present in varying degree from any viewing angle, but is only objectionably noticeable when the viewing angle becomes sharp.

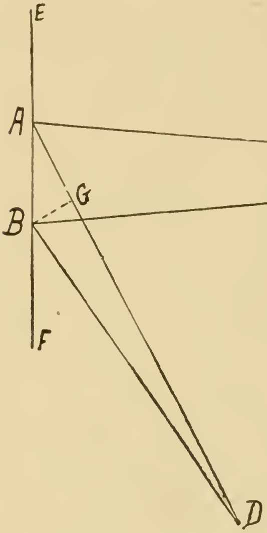


Figure 113

(33) No screen surface can remedy this condition. Reducing the viewing angle is the only remedy. When there are viewing angles such as shown in Fig. 113 exhibitors should install a screen of high diffusion power. As a matter of fact such angles should not exist in any motion picture theatre.

(34) According to Table No. 3 on page 229, the only screen for the theatre layout previously mentioned would be E. We need a surface approximating E in diffusion power, with the highest reflection power possible.

Screen Mounting

(35) The best screen mount is a strong frame with metal hooks, metal eyelets, and a rope lacing. It keeps

the screen stretched tight and flat and permits it to be taken out conveniently for restretching.

CLEANING SCREENS

(36) Do not accept any statement from a salesman or manufacturer that a screen surface can be cleaned to regain its original reflection powers. It cannot be done with any screen surface. Some surfaces when cleaned for the first time do regain a large percentage of their original values, but each time the cleaning process is repeated those values diminish. This is true even with glass bead screens. The beads themselves may be cleaned perfectly but there is the material in which the beads are embedded which is also a part of the reflecting surface and which loses reflecting power with each successive cleaning.

(37) Except glass, any substance now used for screen surfaces undergoes a chemical change with the passage of time. The change may be slow but it is steadily progressive.

(38) Some patent screen surfaces can be refinished successfully. There are now companies that make a business of re-surfacing screens. In any case the theatre owner should make sure about such claims.

PERFORATIONS

(39) From twenty to forty holes are punched in every square inch of screen surface. Thirty holes per square inch (144 × 30) totals 4,320 holes per square foot, or 1,049,760 holes in an 18 × 13.5 foot screen surface.

(40) Screen surface area reduction by perforation runs between 9 and 10 percent. To compensate for the loss of so much reflecting area, at least 9 percent more electrical energy must be used to secure screen illumination equal to that provided by a solid surface of equal reflection power. There is no compensation, however, for the loss in picture details, which is estimated to be about 10 percent.

(41) Perforated screens were introduced to permit the passage of sound from loudspeakers behind the screen, and are a necessity even though they reduce the intensity of both light and sound. The construction of present day loudspeakers is such that they cannot be located around the edges of the screen as was occasionally done with earlier types of speakers. Even if this were possible with modern speakers it would be undesirable as impairing the illusion of naturalness for patrons in the forward seats—they would realize that the sound was not coming from the screen.

How to Obtain Viewing Angles

(42) It is an easy matter to calculate the viewing angle from any portion of a theatre to the center of the screen. No special equipment is required. Make a mark in the horizontal center of bottom of the screen, calling it point A. From this mark measure the distance, in inches, to the center of the back of the seat for which calculations are being made. Call this point B. From point A stretch a line back at exactly right angles to the screen surface, a distance a little more than equal to the distance from point A to point B. Use a good carpenter's steel square to get the angle. Anchor this line to a board laid across the center aisle on the

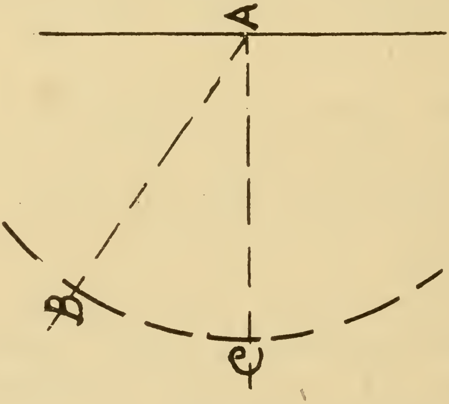


Figure 114

chair backs. From point A measure along this line a distance equal to the distance from point A to point B, and tie a string to the line. Call this point C. Next from point B measure the distance to point C. The plan is shown in Fig. 114.

We now have points A, B and C established. Next multiply two times the distance, A to B, in inches, by 3.1416, and divide by 360. The result will be the length, in inches, of one degree of the circumference of a circle, the radius of which is the distance from point A to point B. If we now measure the distance from B to C in inches, and divide by the length of the degree, we arrive at the number of degrees point C is from the center line of the theatre. This is termed the "viewing angle." The same calculation may be made from any point in the auditorium to any point on the screen.

Because we have measured in a straight line from B to C, our answer will not be precisely correct, but near enough for all practical purposes. If an exact calculation is desired, lay several short, wide boards on the chair backs along the arc of the circle found by swinging point C (mark on line) around from C to B. Trace the circle along the boards and measure the length of the arc exactly.

PERFORATED SCREEN MAINTENANCE

(43) Perforated screens present some special difficulties in maintenance owing to their perforations.

They require more frequent cleaning and refinishing than solid surfaces because the air circulating through the hundreds of thousands of tiny holes leaves a deposit of dust in the walls and around the rims. Discolorations caused by gases soon appear, inducing the reflecting power of the screen to diminish rapidly. It is more difficult to clean a perforated screen than a solid one. Without a suitable apparatus and experience it is equally hard to refinish a perforated screen without reducing the perforation diameters or filling them in completely, thus reducing volume and (or) setting up uneven distribution.

Distance of Screen to Front Seats

(44) Too little distance from the front row of seats to the screen sets up a wide viewing angle, which is bad. It also tends to decrease sharpness of the screen image when viewed from the front seats. In general it tends to destroy the illusion that speech comes from the lips of the players.

(45) The front row of seats should never be closer than 20 feet from a 16-foot picture. If the screen is larger add one foot three inches of additional distance for each foot of additional screen width.

Taking this as a basis, it is a simple matter to calculate the distance required for any picture width. The greater the distance from the front seats the more comfortably the people sitting there will enjoy the picture. It must not be carried to excess as it would accomplish no good purpose except to reduce seating space unnecessarily. There is no eye-strain involved for those of normal eyesight located one hundred feet from a well-illuminated 16-foot picture. This distance may be accepted as a safe guide.

Height Above Floor

(46) Height of screen above the floor depends largely upon local conditions. It is usually best to have the picture located as low as possible without concealing the view of its lower portion from any seats in the auditorium. The chief objection to height is that it detracts from complete naturalness. A good picture perfectly projected helps the audience forget that it is facing a make-believe world and creates an illusion of real people in real life. The position, size and illumination of the screen are factors that help to create this illusion.

Picture Size and Light Demand

It is well known that if the front seats are too close to a large screen the image will lack sharpness. It will have a "fuzzy" appearance. This is the natural effect of the tremendous magnification of the film photograph when viewed too closely. It is very hard on the observers' eyes and detracts from the enjoyment of the picture. Again, when placed too close to the screen the theatre patron must cover an excessively wide viewing angle, which is very hard on the eyes. He is also subjected to a foreshortening effect as illustrated in Fig. 113, if seated in one of the end seats.

(47) As screen image dimensions are increased the amount of light must also be increased to maintain the brilliancy of illumination.

(48) A study of percentage factors of illumination for various sized screens reveals a startling differential which must be counterbalanced by a proportional increase in light energy. The accompanying table tells the story at a glance. Let us take a screen size of 10 × 12 feet as a unit of measurement. We will assume that the illuminating factor of this screen under proper conditions is 100. If the same amount of light is projected on screens of increasing sizes the drop in illuminating values is as follows:

10	×	12	=	120	sq. ft.	100	percent
12	×	16	=	192	sq. ft.	39	"
12.75	×	17	=	216.75	sq. ft.	34	"
13.50	×	18	=	243	sq. ft.	29	"
14.25	×	19	=	270.25	sq. ft.	27	"
15	×	20	=	300	sq. ft.	25	"

(49) Moreover, increase in picture dimensions require a very rapid magnification of the film photograph.

(50) The linear magnification may be determined by dividing the width of screen image, in inches, by width of the projector aperture.

(51) The larger the screen the more quickly defects in the film will be sighted by the audience, if a brilliant illumination is maintained.

(52) There is no advantage gained from mere size or from brightness of illumination unless it is required by the conditions of the theatre. A very bright picture is unquestionably very hard on the eyes. Subdued illumination may be just as hard because of the straining after the darker details in the screen image. A properly illuminated 16-foot picture has better visibility than an

inadequately illuminated 20-foot picture, and the smaller picture will be more pleasing to those in the front seats.

(53) Most theatres would be best served by a screen 18 feet wide, although large theatres have gone in for larger screens on the theory that the size of the picture is related to the size of the auditorium. While this is true up to a certain point the real relation is between the screen and its immediate surrounding area, particularly if it is an unbroken wall. If this surrounding area is broken up and decorated in a series of small areas the small screen will be proportional from all parts of the theatre. Better than a large screen, the small one offers a compact film image which, when properly illuminated, is pleasing and effective from all parts of the theatre. Small pictures are unsatisfying when they do not conform to surroundings.

There is no undue eyestrain in viewing a well illuminated sixteen foot picture at 100 feet. As a matter of fact, a sixteen foot picture can be viewed comfortably at an even greater distance, with no eye fatigue, provided the screen is properly illuminated. (54) No matter how small the theatre the width of the screen should not be less than ten feet. As already indicated only a very large theatre of 4,000 to 6,000 seats requires a screen image larger than eighteen feet.

Tinting

(55) Tinted screens were first used to neutralize harsh light rays to give the screen image a softer effect. But since films are sometimes made on tinted stock and also because we are getting an increasing number of color films, tinted screens today are of questionable value. Projecting a color picture on a tinted screen may result in a bizarre effect. It is safest to undertake no experiments with tinted screen surfaces.

Location and Surroundings of Screen

(56) If the screen is located on the stage it should be as far back as conditions will permit. A rear location

will help reduce the projection angle and make vision from the front seats more comfortable.

(57) If there is a stage, the portion in front of the screen should be covered with a black cloth or painted a non-gloss black.

(58) Provided the viewing angle from the front seats is not too great the screen may be located in "one" with good effect, but whatever the location it is extremely important that its surroundings be inconspicuous. No object must distract the eye while the picture is on the screen.

(59) The border should be plain non-gloss black next to the picture. This may be shaded gradually over a distance of not less than three feet into some lighter tone (silver gray) in harmony with the surroundings.

The theory has been advanced that the sharp contrast between a black border and the white light tends to raise the apparent screen illumination near the edges of the screen above its center.

This might be true were the screen evenly illuminated, (60) but as a matter of fact screens are not evenly illuminated under the best condition. Illumination is always highest at the screen center. It falls off sharply to the outer margins. The difference is often as much as fifteen c. p. at center and as low as five at the margins. The effect of sharp border contrast therefore would be to level the illumination for all parts of the screen.

A dead black border next to the screen allows the picture edges to overlap upon it an inch or two. This tends to make less visible any movement of the screen image as a unit.

Paint and Kalsomine

Perforated screens cannot be improvised. Exhibitors must choose the one that most nearly meets their requirements from the generous supply of many types now on the market. (61) Wise exhibitors will exercise due care in making selection, demanding suitable written guarantee that statements made by salesmen will be backed up by the manufacturer.

It must be conceded that in some small villages and towns there is not sufficient patronage available to justify installation of high grade, expensive screens, therefore if it is hoped to make expenses and clear any profit at all, moderate price equipment must be selected, and investment kept at the lowest point consistent with acceptable results in screen image and sound.

Constructing a Screen

(62) Wherever there is sufficient possible patronage it is always best to install high grade equipment and produce the very best results that can be attained. But there are equipments in the lower price brackets that, competently handled, give very good account of themselves. It is even possible to construct a screen that, while not equalling reflection surfaces scientifically manufactured, will deliver results quite acceptable in the village theatre, and have the added advantage that the reflection surface may be renewed at very small cost.

Constructing the Screen and Frame

(63) The base should be heavy, unbleached muslin, cut into lengths about three feet wider than the screen image is to be. The seams must be very straight and carefully made. The height should be three feet in excess of what the screen image will be, the excess to provide space for a black border. The sheet as a whole must have metal eyelets located every six inches all around its edge. It is very much better to purchase the sheet, since making it properly would be a very difficult task for a theatre man.

(64) The day of stretching a cloth screen on a timber frame and nailing it there has passed. Modern practice demands a frame sufficiently heavy or well braced that its top, bottom or sides will not bend inward when subjected to the strain of stretching the screen thereon tightly. This frame may be of wood or metal, but must be equipped with strong metal hooks corresponding in position with the metal-lined screen eyelets. By means

of a small rope reaved through the screen eyelets and attached to the hooks, the screen may be mounted and stretched both evenly and as tightly as may be desired; also it may be restretched as often as may prove necessary.

(65) Having thus mounted the raw muslin, it must be thoroughly wetted (using a paint or kalsomine brush) with a glue size made by dissolving one or two pounds of glue (according to quality thereof) in a pail of hot water. When it is thoroughly dry, paint it once more with the sizing. When the second sizing is dry the screen is ready to receive its reflection surface.

(66) Mix some white lead ground in oil with one half boiled linseed oil and one half turpentine. Add enough ultramarine or prussian blue to cause the paint to have a very faint bluish tint while in the pot. This kills tendency of the paint to show a slight amber tint, acting the same as does blue in laundry rinse water. Apply a fairly heavy base coat of this paint and allow it to dry completely. Next mix one half white lead ground in oil and one one half zinc white ground in oil, with one third boiled linseed oil and two thirds turpentine, adding blue as before. Apply a very even coat of this and allow it to dry. Project the white light and paint on a border of non-gloss black, unless it be preferred to construct a border of black or suitably colored cloth.

Please understand, we do not commend this procedure except in places where restricted possibility of patronage compels the strictest economy.

KALSOMINE REFLECTION SURFACE

In lieu of paint a type of kalsomine sold under the trade name "Alabastine" may be employed with quite satisfactory results, though it has not quite as high a reflection power as has properly mixed paint. It has the advantage, however, that it may be washed off and wholly renewed as often as may seem advisable.

Both the paint and kalsomine surface screens are solid surfaces, hence the loud speakers cannot be located behind them, but only at the top or the screen side.

RECOATING PERFORATED SCREENS

(67) When it becomes necessary to recoat a perforated screen, it should be sent to the manufacturer or be done at the theatre by his own men. The exhibitor can attempt it himself but the results cannot be guaranteed. (68) The difficult thing is to avoid partially filling in the perforations.

Either paint or kalsomine should be used—these being the best for coating when the job is undertaken by the theatre. (69) If paint is to be used, try a small section at one of the bottom corners. If it adheres, apply it as suggested below. (70) If it doesn't adhere, wash it off carefully with a soft rag dipped in turpentine. Try shellac the same way. If it sticks, apply a thin veneer all over the screen surface, let it dry and then apply a thin coat of paint.

(71) When coating a perforated surface, the perforations can be kept partially free with the aid of a suction hose attached to a vacuum cleaner operating on the other side of the screen, working in time with the movement of the brush. The regular dust bag of the vacuum should be replaced by gunny sacking. If there is no room for the operation back of the screen, the screen should be dismounted and stretched on a temporary frame. (72) A spray gun for the resurfacing job is much better—it will not clog up the perforations as much as a brush does. In any case, the size of the holes must not be decreased or it will have a bad effect on the sound.

If kalsomine is used instead of paint follow the same general method but apply thin coats only. Never put heavy coating on perforated surfaces.

SCREEN SIZES

(73) The Projection Screens Committee of the Society of Motion Picture Engineers suggests the following screen sizes as best for present-day projector aperture dimensions. The height and width are as 3 and 4. For an 18 degree projection angle such a screen will require a minimum of masking.

TABLE NO. 4. SCREEN SIZES

8′ × 6′
9′ × 6′ 9″
10′ × 7′ 6″
11′ × 8′ 3″
12′ × 9′
13′ × 9′ 9″
14′ × 10′ 6″
15′ 11′ 3″
16′ × 12′
17′ × 12′ 9″
18′ × 13′ 6″
19′ × 14′ 3″
20′ × 15′
21′ × 15′ 9″
22′ × 16′ 6″
23′ × 17′ 3″
24′ × 18′
25′ × 18′ 8″

(74) Authorities believe that the auditorium illumination should be approximately 0.18 of a foot candle, approximating the illumination necessary to read theatre programs printed in 8-point type. It is sufficient to enable patrons to locate seats. It does not greatly affect contrasts of light and shade on the screen.

(75) The picture is a matter of contrasting shades. Rays from an auditorium light falling upon the screen illuminate all parts. These rays do not alter the white portions, but they light up the deeper tones and thus reduce contrasts.

(76) Permit no direct rays of light to reach the screen from any source other than the projection lens. Permit no "glare spot" of light within view of the audience.

(77) A "glare spot" is a concentrated spot of white light of considerably higher brightness than surrounding objects and has a bad effect both upon the eyes and upon the screen image.

(78) Viewing comfort is ability to see all details of a picture without strain. It is attained by a combination of brightness and area. Viewing may be made more comfortable for the eyes either by increase in picture area or by increase in screen brightness. Viewing comfort is ability to see all details of a picture without strain.

THE FILM

Practical Questions

(For answer to each question see statement of corresponding number in Chapter XI)

1. What two different kinds of 35 mm. film are there?
2. What is the width of film in inches?
3. What are its other dimensions?
4. Describe, in general, the process of manufacture.
5. What are the photographs impressed thereon?
6. What are the dimensions of a film "frame"?
7. Exactly what length of film is occupied by each frame?
8. What are the present approved dimensions of the motion picture projector aperture?
9. Upon which side of the projector aperture is the sound track located?
10. Is the picture over the projector aperture upside down?
11. How wide is the sound track?
12. What two different methods of sound impression are used?
13. Which is the R.C.A. method and which the Western Electric?
14. Is the sound impressed on the film simultaneously with the picture?
15. Is the sound impression on the film always in perfect synchronization with motion?
16. By whom is the film perforating usually done?
17. How many perforations are there to each frame?
18. How many frames are there to each foot of film?
19. How many perforations are there to each foot of film?
20. Has the projectionist important rights with respect to the film?
21. What are the obligations of a film exchange?
22. Does the exchange hold itself responsible for sending theatres clean and safe film?
23. Are projectionists responsible for accidents resulting from bad film sent by the exchange?

24. Is it the duty of the projectionist to repair films received in damaged condition?
25. Is it the duty of the projectionist to repair film damage originating in his own projection room?
26. Name nine principal causes of damage to film.
27. How may such damage be avoided by the exchange in co-operation with the projectionist?
28. For what reasons do mismatched sprocket holes inflict damage upon films?

Splicing Film, page 257

29. Is a poorly made splice likely to cause damage to film?
30. Upon what does a perfect film splice depend?
31. Name the procedure necessary to make a good splice.
32. What will happen to film cement if it is exposed to the air?
33 How should cement be applied?
34. What is vitally necessary in making a good splice?
35. Is heavy, evenly applied pressure essential in making a splice and for how long must pressure be exerted?
36. What will be the result if too little or an uneven pressure is applied?
37. Can a proper splice be made without the aid of a splicer?
38. Does dry scraping of the stub end in making splices produce reliable results?

Storing Films in Theatre Projection Rooms, page 261

39. Should other things beside fire hazard be considered in storing film?
40. To keep film pliable must it be stored in a humid air?
41. What operates to drive moisture out of film quickly?
42. How can the moisture content be restored?
43. Are water tanks filled by hand efficient?
44. Describe some requirements of an efficient film storage cabinet.

Handling of Film, page 263

45. What is the first duty of the projectionist as soon as his film arrives?

46. Should the projectionist notify the theatre manager and the exchange manager of the condition of newly-arrived film?
47. If the exchange fails to heed complaints, what other agencies should be notified?
48. Where should all film, not in the projector, be kept?

How to Rewind Film Correctly, page 264

49. What is the minimum time required to rewind 2,000 feet of film properly?
50. Is low speed rewinding of benefit to the projectionist?

Rewinder, page 264

51. Where should the rewinder be located?
52. Why is it undesirable to locate the rewinder away from the projection room?

Rewinder Details, page 265

53. How may a piece of ordinary glass be ground?
54. Must the rewinder elements be in perfect alignment?
55. Do rewinder elements out of line damage the film?
56. Is a rewinder tail reel brake necessary?
57. Is a switch to stop the rewinder automatically necessary?
58. How may pulley sizes to reduce rewinding speed be calculated?

Film Shipment Reels, page 267

59. Name the points of importance with regard to shipping reels.

Projection Room Reels, page 267

60. Should the use of a set of projection room reels be made mandatory?

How to Estimate Footage of a Roll of Film, page 268

61. Why is it impossible to calculate the footage of a film roll accurately?
62. How can a fairly accurate estimate of footage be calculated?

63. How may the footage be calculated with the aid of the projector mechanism?

REMOVAL OF EMULSION, PAGE 268

64. How may emulsion be removed from film?
65. What is the best method for cleaning film?
66. Is film cleaned with gasoline or benzine?

RAIN, PAGE 271

67. What is "rain"?

KEEP THE FILMS CLEAN, PAGE 271

68. Is it possible to prevent oil from reaching the film?

STANDARD RELEASE PRINT, PAGE 272

69. Of what does the change-over cue consist?
70. Is the dowser operated the instant the change-over cue apappears on the screen?
71. How may projectionists make visibility of cue mark easy and certain?
72. Of what does the motor-start cue consist?
73. Why is the motor-start distance to the change-over twelve feet and six frames?
74. Describe process of ascertaining the exact motor pick-up speed.
75. How can the correct start-frame number for each projector be ascertained?
76. Will motor pick-up speed always be the same?
77. Must motor pick-up speed be ascertained for each projector?
78. How is the standard release print started?
79. Can the standard release prints be used to check for synchronism?
80. How can exact synchronism be assured?
81. Do cut-outs work injury to standard release print performance?

CHAPTER XI.

THE FILM

(1) The 35 millimeter-wide motion picture film is usually nitro-cellulose (inflammable), though cellulose acetate (slow-burning) is available. The two are exactly the same, except for their ingredients. (2) The 35 mm. film is 1.376″ to 1.378″ (practically 1⅜ inch) wide. (3) Its various dimensions, as approved by the Society of Motion Picture Engineers, may be examined in Fig. 116.

(4) Celluloid, from which films are made, is manufactured in wide sheets approximately 2,000 feet in length. These sheets are coated with photographic emulsion, some negative and others positive, according to their purpose. They are then split into ribbons 35 mm. wide and perforated. The combined thickness of the film stock and the photographic emulsion is from five and one-half to six thousandths of an inch. The photographic emulsion is about 0.001 of an inch thick.

(5) The camera impresses a series of snap-shot photographs upon a negative film at the rate of 24 per second. (6) The over-all dimensions of these "snap-shots" are 0.631 inch by 0.868 inch. The chief difference between the negative impression and the photograph on the positive print is that everything is in reverse, the clear whites in the negative will be opaque blacks in the positive, and opaque blacks in the negative will be clear white in the positive print, with graduated shading of tone. (7) In both negative and positive, each photograph and its surrounding dividing line (known as the "frame line") occupies precisely 0.75 (¾) of an inch, or 16 "frames" to each foot of film.

(8) Today the dimensions of the motion picture projector aperture, as approved by the Society of Motion Picture Engineers, are .600 by .825 of an inch. Note that

the motion picture projector aperture is smaller than the photographs on the film.

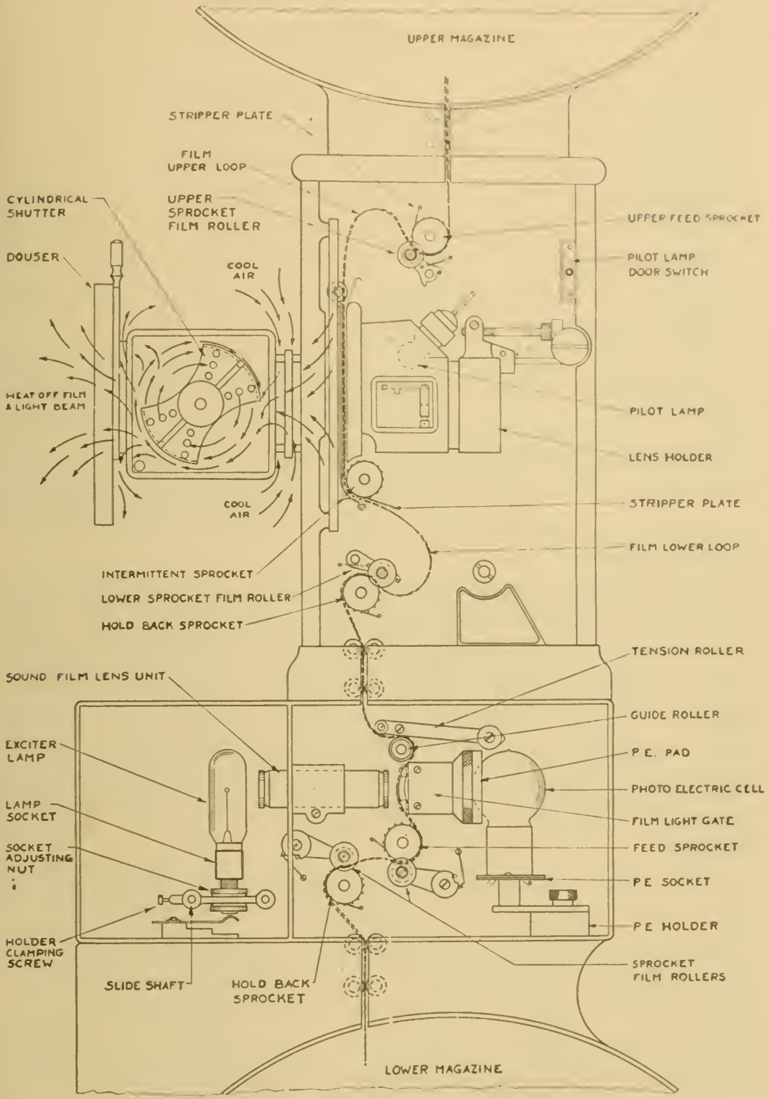


FIG. 115.—Path of film through Motiograph DeLuxe projector and sound head.

In Fig. 116 we see the film, emulsion side toward us, with the image, were there one, upside down. In other words, if we look at the film from the emulsion side, with the picture wrong side up, the sound track will be at the right, as in Fig. 116, in which it is labeled "scanned area." (9) It will be on the right side when the film is in the projector, (10) the film always being threaded into the mechanism with the image upside down. (11) The sound track is 0.084 inch wide, with an allowable tolerance of error of 0.002 inch. (12) The sound is photographically impressed upon this sound band, either in the form known as "variable area" or "variable density," (13) the first being the RCA method, the second the Western Electric method. These two methods are explained on page 429.

(14) The sound impression may be made on a film simultaneously with the photographing of the scenes—but on a separate negative or, as the news reels do, simultaneously on the same negative—or they may be made at separate intervals. In any case, the sound and the image are in synchronism when they are combined in the positive print.

(15) When sound and scenes are made at different intervals of time the lip movement may not be in exact synchronism with the sound, though close enough so that the audiences detect no imperfection. Where sound and picture is impressed upon separate films, as is usually done, there are certain guiding synchronizing marks impressed on each so that when the sound and picture are later combined in the positive print the effect is perfect.

(16) The producer may purchase unperforated stock and perform the perforating operations in his laboratories though most producers use perforated stock, both negative and positive. (17) There are eight perforations, or sprocket holes, to each frame of pictures, four on each side. (18) There are sixteen frames and therefore (19) 128 perforations, 64 to a side, to each foot of film.

(20) It is important to examine the rights of the projectionist concerning the film while it is under his charge and what he has the right to expect from the film ex-

change in clean prints in a good state of repair that may be safely projected.

What an Exchange Contracts to Do

(21) When an exchange contracts to supply film service to a theatre it agrees, unless for some reason it is otherwise stipulated, to provide (a) prints in first-class condition, safe in every way for the grueling grind through the projector for hours each day. Automatically the exchange becomes morally and legally responsible for fire or other accident that results from faulty prints, though it must be noted that the projectionist is not relieved from the duty of inspecting the prints before starting operations for the day. (b) The exchange also undertakes to provide clean film. (22) It becomes a reasonable assumption that the exchange holds itself responsible for providing the theatres with clean and safe working prints.

(23) It is equally evident that the projectionist cannot legally be held responsible for accidents resulting from imperfect prints nor for a poor screen image and bad sound because the prints are oily and dirty.*

(24) Inasmuch as the projectionist is never relieved from his moral duty to provide the utmost safety for the people in his theatre, it is nevertheless one part of his duties to make repairs on film received imperfectly from the exchange. (25) It is, moreover, decidedly the projectionist's duty to repair all damages done to the film while it is in his possession and to return the prints in as good a condition as received.

Cause of Damage To Films

(26) Films may be damaged in many ways. The principal causes are:

Shipment to or from theatres without proper packing and/or rough handling while in transit.

Damage to sprocket holes because of worn sprocket teeth and/or too much tension at the projector aperture or take-up. Excessive tension works a great deal of damage, especially if the sprocket teeth are hooked or undercut.

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*These statements were examined and fully discussed by the Projection Practice Committee of The Society of Motion Picture Engineers at a regular meeting held March 7, 1934, and were unanimously approved.

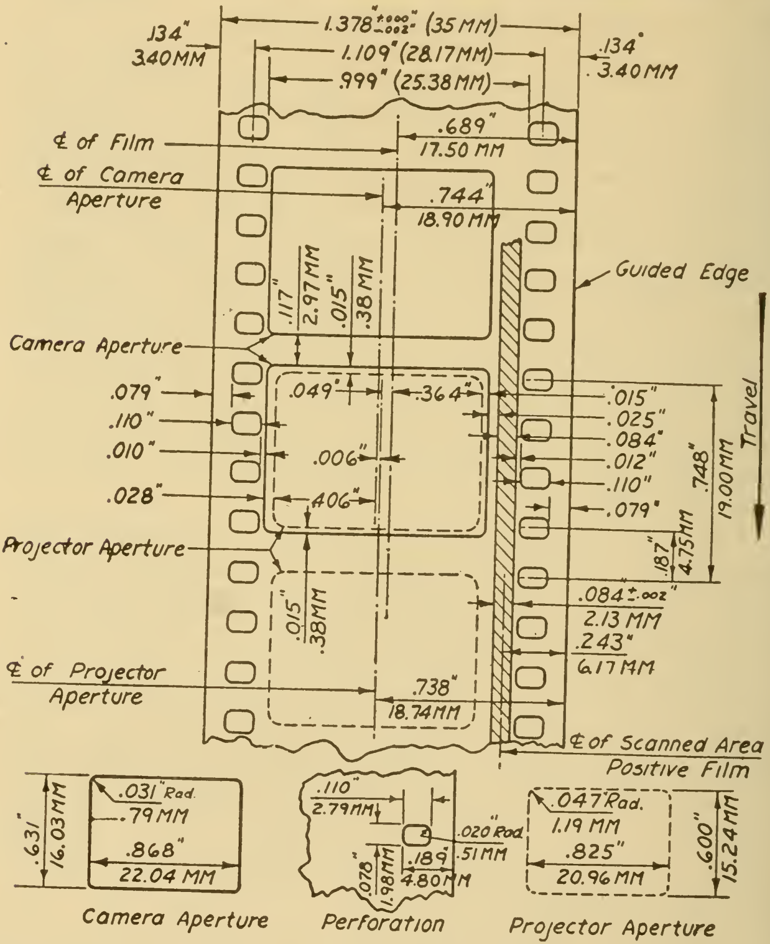

FIG. 116.—35 MM. Sound Film showing camera aperture, projector aperture and scanned area. These dimensions and locations are shown relative to unshrunk raw stock. Positive; emulsion side up. Negative; emulsion side down. In the camera the emulsion side of the film faces the objective. Viewed from the objective the sound track is to the left. In the projector the emulsion side of the film faces the light source. Viewed from the light source the sound track is to the right.

Imprint of the sprocket teeth on the film brought about when the film runs off the sprocket, which may be caused by badly adjusted sprocket idlers, poorly made splices, loose splices and by other means.

Scratches in the emulsion due to rewinding without a proper tail reel brake, which requires that the film roll be pulled down by holding one reel stationary while the other is being rotated; by bits of emulsion or film cement that stick to the projector parts, the emulsion side of the film rubbing against them in its passage through the projector.

Dry and therefore brittle film which is easily susceptible to damage.

Excessive speed of rewinding, particularly if the rewinder elements are out of line with each other.

Loose splices caused by improper scraping of the emulsion from the front and careless removal of oil or dirt from the back of the splice or by poor or damaged film cement. Too much or too little cement is also bad. Insufficient or unevenly applied pressure upon the splice while it is "setting" is often the cause of trouble.

Punching, scratching or pasting on of change-over marks.

Punching of identifying marks on the film by the exchange which the projectionist must remove to avoid their appearance upon the screen.

(27) All the foregoing types of damages to film and, additionally, many others, may be avoided if the exchange and the projectionist conscientiously exercise care in their handling of prints.

Prints should be packed in shipping cases tightly so that they cannot move around when in transit.

Reels should not be overloaded with excessive footage.

The outer layer of film should be protected by paper bands pulled tightly and well secured.

Proper inspection should be made at the exchange to repair loose splices, untrimmed or cracked sprocket holes and torn parts, particularly, tears or cracks at the divisions between sprocket holes.

Rewinder elements in the projection room should be in perfect alignment so that the film will not rub on either side of the reel.

Film should be rewound at the rate of six minutes for each 1000 feet of film—and no faster.

Avoid excessive tension by properly setting the tension at the projector aperture and at the take-up.

All sprocket idlers should be adjusted properly.

All sprocket idlers should rotate easily and smoothly so that they will not wear flat on one side.

Watch all sprocket teeth and replace them at once if they show signs of hooking or undercutting.

Allow no scraps of emulsion or bits of film cement to accumulate on any portion of the projector film track.

Maintain proper tension upon the reel in the upper magazine to avoid overrunning of the film and the consequent jerks when the slack is taken up.

When running soft, new film, watch out for collection of scraps of emulsion and film cement upon the tension shoes. These deposits generally come from too much tension at the aperture.

Make splices carefully following the procedure outlined on pages 258-261.

See that the reel that is being rewound has enough tension to make the film fit snugly on the other reel, eliminating the constant "pulling down" process by hand which is the cause of much damage to film.

Keep the projection room perfectly clean. Dust in the air settles upon and scratches the emulsion side of the film.

And above all do not permit untrained assistants to make splices or other repairs to the film. A great deal of trouble is started that way.

(28) Mismatched sprocket holes resulting from careless splicing do much damage. They will "clamp" or stick on a sprocket tooth and pull the film around the sprocket. Often sprocket teeth will climb out of the sprocket hole and travel along the face of the film, making indentations that will show up on the screen or be heard in the auditorium, if the sound track has been defaced. Mismatched sprocket holes at a splice cause the screen image to jump every time they pass over the

intermittent and tend to give a side motion to the screen image as they pass the aperture.

SPLICING FILM

Bad splicing is the source of more trouble than almost any other factor. The varieties of damage it causes film are almost too numerous to count. (29) For example, a splice that tears loose at one side only lets the edge of

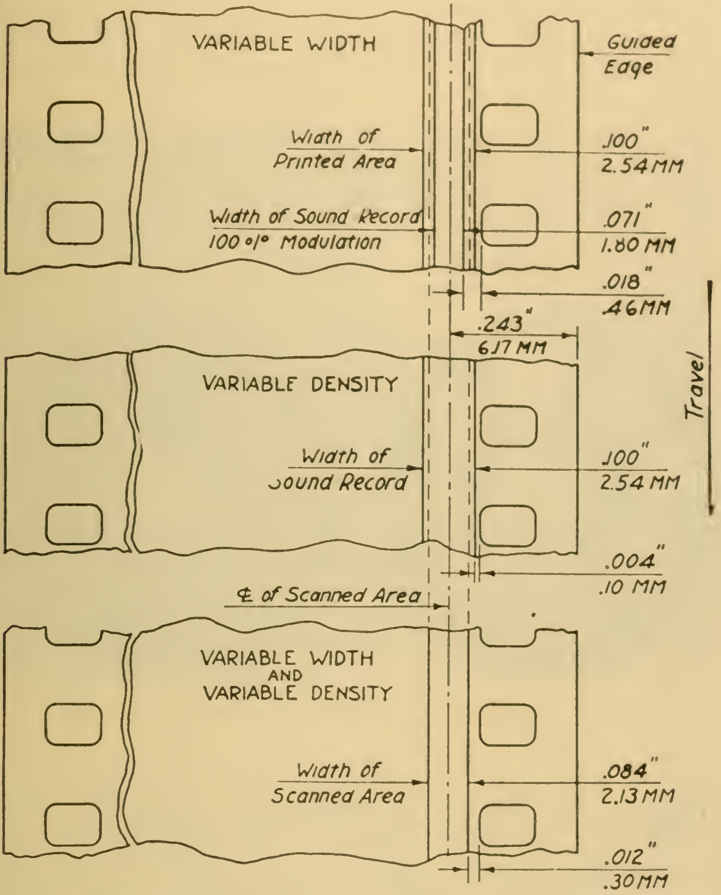

FIG. 117.—35 MM. Sound Film showing sound records and scanned area. These dimensions and locations are shown relative to unshrunk raw stock. Positive; emulsion side up. The dimensions as shown include the necessary allowance for film weave.

the film catch on a sprocket idler, either ripping the film in two or splitting it down its length for several feet. It stops the show and creates a dangerous fire hazard. (30) Three factors are important in the making of a good splice: careful, intelligent work, good film cement and the proper tools.

The day of hand-made splices is past. The several film splicers on the market all give good results and one of them should be in every projection room.

(31) In making splices, film ends should be cut at the right place and cut square. The stub end must be exactly the right length; if it is too short it will be weak and if it is too long it will be stiff. Scrape the emulson from the stub end exactly to the center of the frame line and no further. The line at the end of the scraping must be straight and at right angles to the length of the film. Scrape to the proper depth so as to remove all the emulsion and slightly roughen the celluloid beneath. If the emulsion is not all scraped away the splice will not hold. If the scraping is too deep it will weaken the film. If the film is dry and inclined to brittleness the splice will break after a short time. These are factors that have to be watched carefuly in the process.

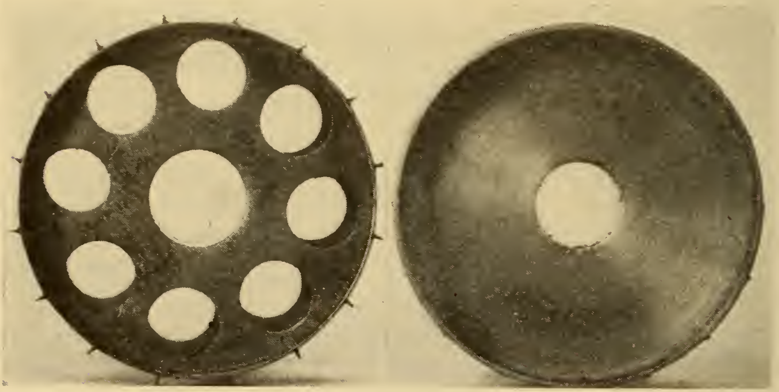

Fig. 118.—Examples of worn intermittent sprocket teeth

The rear or celluloid side of the film must also be scraped slightly to remove dirt and oil and to roughen the celluloid a little.

Above all use good cement.* If it is kept from contact with the air it will remain in good condition for a long time. (32) If cement is exposed to the air it will evaporate some of its content, absorb moisture quickly and make very weak, poor splicing material.

(33) Film cement is not rubbed on. It is applied with a small brush. Do not pass the brush across the film more than once. No satisfactory explanation has ever been forthcoming why more than one brush stroke of cement across the face of a film weakens the splice but long experience in projection rooms points to it.

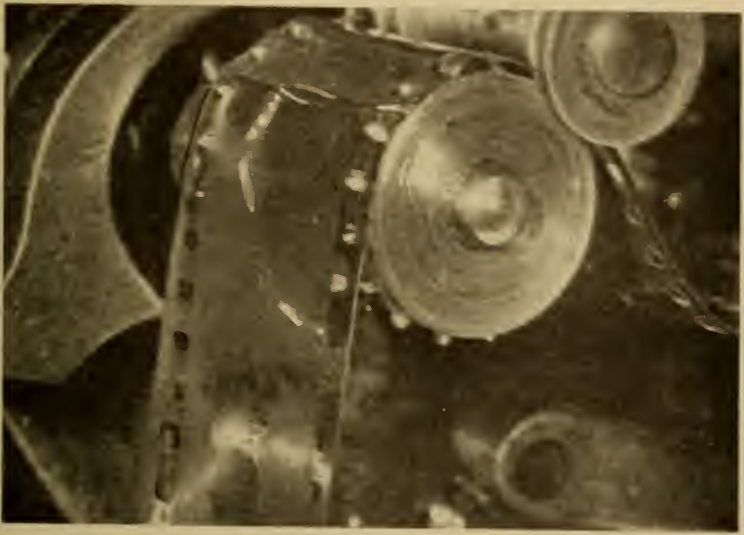

FIG. 119.—Example of stiff, wide, splice going over sprocket. Observe how film is raised off face of sprocket; the image on the screen passes through a series of convulsive movements.

(34) To make a strong splice the cement should be laid on with one stroke of the brush—an application that requires skill and judgment, which come from practice.

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*Non-flammable or slow-burning film cannot be spliced with the usual cement used for flammable stock. It requires a cement especially made for the purpose.

(35) Join the two ends and apply an even, heavy pressure for at least five or six seconds—while you count six slowly. (36) Lack of sufficient pressure, or pressure unevenly applied, will result in a weak or otherwise imperfect splice. Excessive pressure, no matter how much, will do no harm.

(37) It is impossible to make a really good splice with the unaided hands for the reason that the film, most probably, will not be cut square or have a correct stub end length; also the pressure will certainly not be evenly applied. An efficient mechanical splicer cuts both ends perfectly square and cuts the stub end at precisely the correct length. It applies ample, evenly distributed pressure and automatically matches the sprocket holes perfectly.

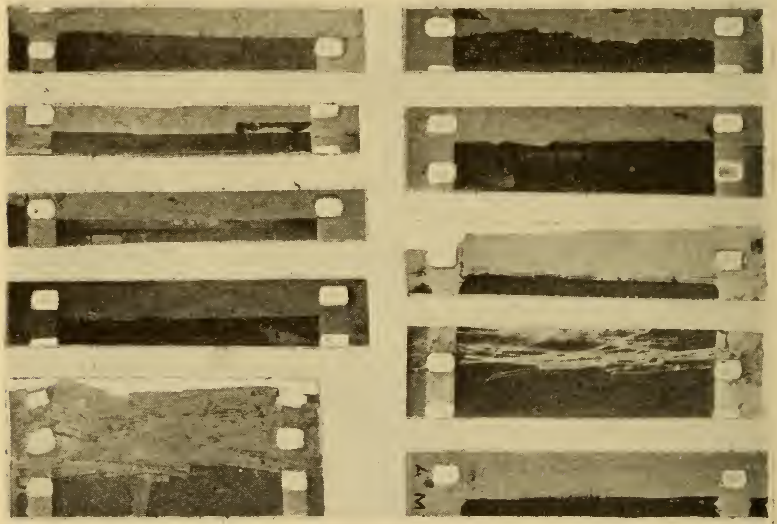


FIG. 120.—Samples of inefficient stub-end-scraping. They are all parts of film splices made in projection rooms.

(38) All forms of dry scraping of stub ends in making a film splice are unreliable, because the emulsion is only approximately 1/1000 of an inch thick, and it is obviously impossible for a projectionist to maintain an

adjustment that will remove 1/1000 of an inch of surface, and no more.

A dry metal scraper adjusted to remove just enough surface will wear away slightly after the first half dozen splices so that thereafter a thin coating of emulsion will always remain on the stub end. If it is adjusted to remove a bit more than is necessary, it will weaken the stock and the splice. It is, therefore, better to have a splicer that depends on wet scraping. If this is not available, remove the scraper from the splicing mechanism and perform the operation by hand. In that event provide the splicer with a properly located straight edge.

Wet scraping by hand gives little trouble if the brush and water are handily located and a safety razor blade, clamped in a holder, is used. A good blade holder may be secured in almost any Woolworth store.

The projectionist may construct a home-made splicer, but we advise against it because a home-made affair is not likely to do the job as perfectly as a well designed, well constructed factory-made mechanism.

STORING FILM IN PROJECTION ROOMS

(39) Proper storage of film in projection rooms has been considered heretofore almost wholly from the viewpoint of fire hazard—an error of thought that has cost exhibitors many thousands of dollars that might otherwise have been saved.

(40) New film is very tough and pliable. It may be sharply bent or creased without breaking, a condition that would last almost indefinitely were film always stored in humid atmosphere. But unfortunately it seldom has been in the past either in the exchange or in the projection room.

(41) In the course of projection the intense heat of the spot at the projector aperture raises the temperature of the film, driving out a portion of the moisture it contained. (42) Were the film rewound and immediately stored in an atmosphere of high humidity, at least a goodly portion of the expelled moisture would be recovered.

The storage of film in a humid atmosphere, to be fully effective, must be done in all theatres. Almost every projection room is now equipped with a film storage cabinet, but we believe that few of them have adequate provision to keep the air inside constantly moist. (43) To do so, each cabinet should always contain a body of water. The water surface should be ample to insure sufficient evaporation and keep the air in humid condition. Water tanks that are filled by hand cannot be depended upon to serve the purpose adequately, as they are either neglected or entirely forgotten. (44) To insure proper conditions all film storage cabinets should be

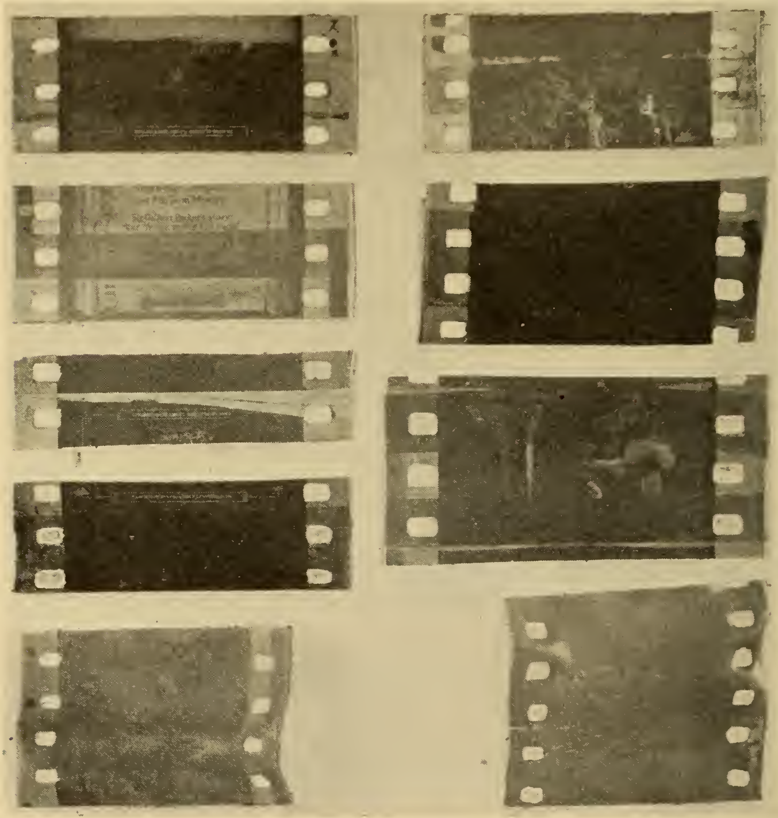


Fig. 121.—Examples of extremely bad film splices.

equipped with a water pan or tank capable of holding not less than thirty-six square inches of water surface for each reel it is designed to hold. The tank should be connected with the water supply and controlled by an automatic valve that will maintain the water level, feeding water automatically to the tank when the water surface drops down to a fixed, pre-determined point. Each tank should be supplied with an overflow, so that under no condition will the water ever reach the film.

Handling the Film

(45) The audience should be the first consideration of the projectionist. Its ultimate safety is the thought uppermost in his mind every minute of the working day. Consequently when film shipments arrive his duty is to make a careful check to discover any likely faults such as loose splices, ripped sprocket holes, etc.; if the film is dirty or streaked with oil it should be cleaned before being put into the projector so as to give patrons pleasing performances as well as safe ones.

(46) If repairs have to be made on prints that have arrived from the exchange ostensibly in good condition, their character and location should be noted and a memorandum sent down to the theatre manager giving the time devoted to making the repairs. A copy of this memorandum should be sent to the exchange manager and if the repairs have been extensive and considerable time devoted to making them, a bill to the exchange would not be out of order.

(47) Whenever an exchange fails to heed the complaint of the theatres and continues to ship out film without the proper inspection and repairs, the matter should be brought to the attention of other agencies which will compel the exchange to handle its film properly: to the local projection union, to the local theatre managers' organization, to local municipal authorities and to the home office headquarters of the film company.

Keep Film Stored

(48) All film not running through the projector or

upon the rewinder should be kept stored away in film cabinets in the order in which the reels are to be used. Local ordinances everywhere demand that the film be stored when not in use and it is also a strict Fire Underwriters' requirement.

How to Rewind Correctly

(49) It requires approximately eleven minutes to project 1,000 feet of film and twenty-two minutes to project a 2,000-foot reel. Film can be safely rewound at about twice its projection speed—but no faster. Projectionists have become accustomed to rewind film at high speed and the habit is hard to break. Generally speaking, 2,000 feet of film should not be rewound in less than ten minutes.

(50) At that speed the rewinding instrument will operate safely without supervision. The rewinder is an important instrument. (51) It should be located in the projection room proper and as near as possible to the film storage cabinet. (52) All so-called safety laws to the contrary, there is no added protection gained by placing the rewinder in a separate compartment. As a matter of fact, the result is sometimes precisely the opposite, particularly in theatres with but one man in the projection room.

By means of properly fused port fire shutters all communication between the projection room and the theatre auditorium, in the event of fire, can be shut off tightly and automatically in a few seconds. If proper arrangements have been made to exhaust smoke and gas as soon as it forms it is likely the audience will be totally unaware of trouble except for the dark screen. But if the rewinder is located in a separate room the chances of fire are greater because the projectionist will often be out of sight of the projectors, despite regulations to the contrary, rewinding his film.

Even where there are two men in the projection room, both may be out of sight of the projectors, examining film on the rewinder. The same procedure, when the rewinder is in the projection room, makes for real safety because the projectors are always in full sight but a few paces away.

REWINDER DETAILS

An opening approximately 2.5 inches by 4.5 inches should be cut clear through the rewinder table top and covered, flush with the table top with a piece of thick ground glass. (53) If no ready ground glass is available, an ordinary piece of glass may be ground down by rubbing it vigorously with No. 00 or 0 emery paper or cloth.

Under the glass install a low c. p. electric light globe operated by a switch conveniently located near by. It will aid in making good film splices. It is not essential equipment in connection with a rewinder but is sufficiently helpful to justify its addition.

(54) If the rewinder you use is not a single unit, that is, if both elements are not mounted on a single metal base, be sure that you set them up in perfect alignment so that the reels are in perfect alignment, too. This is an item that is neglected by many projectionists who should know better.

(55) If the rewinding speed is high, the reels imperfect or the rewinder elements out of line, the film will suffer heavily. When the reels are out of alignment the edge of the film will rub against the reel sides with sufficient force to tip one side of the film up until the sound track is abraded and permanently injured.

It is best to use a single unit rewinder to avoid all possibilities of poor alignment. If separate rewinder elements must be used at least make sure that each is securely fastened to the table top in absolute alignment with the other.

(56) The rewinder element from which the film is being unwound must be equipped with a brake strong enough to make the film rewind snugly though not too tightly. No rule for the amount of braking power can be made; the projectionist must determine that for himself. If the rewinder is an enclosed unit, a brake is always part of its equipment. If separate rewinder ele-

ments, mounted on a table top, are used, the projectionist can make a brake out of simple materials. (57) He should also provide means for the automatic opening of the rewinder motor circuit switch as soon as the film has been wholly rewound. Otherwise the film will continue to run until someone stops it—the end of the film, in the meanwhile, slapping around and being injured. In projection rooms around the country there are examples of rewinder brakes, automatic motor switches and other projection accessories that should be the envy of all engineers and manufacturers.

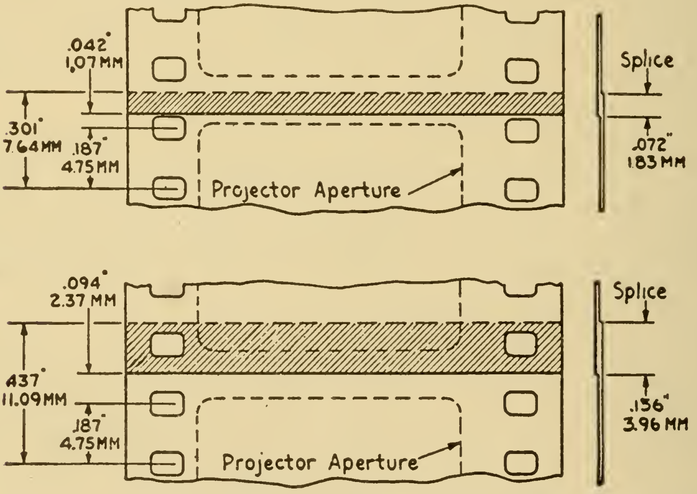


FIG. 122.—Showing properly made splices. Upper illustration is a regular positive splice; lower, is a full hole positive splice.

CALCULATING REWINDER PULLEYS

(58) As already noted, rewinding speed should not exceed the rate of six minutes for each 1,000 feet of film. The rule for computing the speed of pulleys is as follows: multiply the speed of the driving pulley per minute by its diameter and divide the sum by the diameter of the driven pulley. The result is the speed of the driven pulley.

The circumference of the driven and driver pulleys may be used for the calculation instead of diameters. The result will be the same. If we have a motor pulley two inches in diameter (diameter of the face of pulley) running 1,400 revolutions per minute, and propose to drive a countershaft pulley six inches in diameter, we have 2 × 1,400 ÷ 6 = 466.6 revolutions counter shaft would run per minute. If we then propose to drive a 10-inch diameter pulley mounted on a rewinder with a six-inch diameter countershaft pulley, the reel upon which the film is being rewound would run 466.6 × 6 = 2799.6 ÷ 10 = 279.96 revolutions per minute.

Stated in proportions—the diameter of the driven pulley is to the diameter of the driver pulley as X is to the revolutions of the driver pulley. For the solution, multiply two extremes (end quantities) and divide by the known middle number. Result will be the revolutions per minute of the driven pulley.

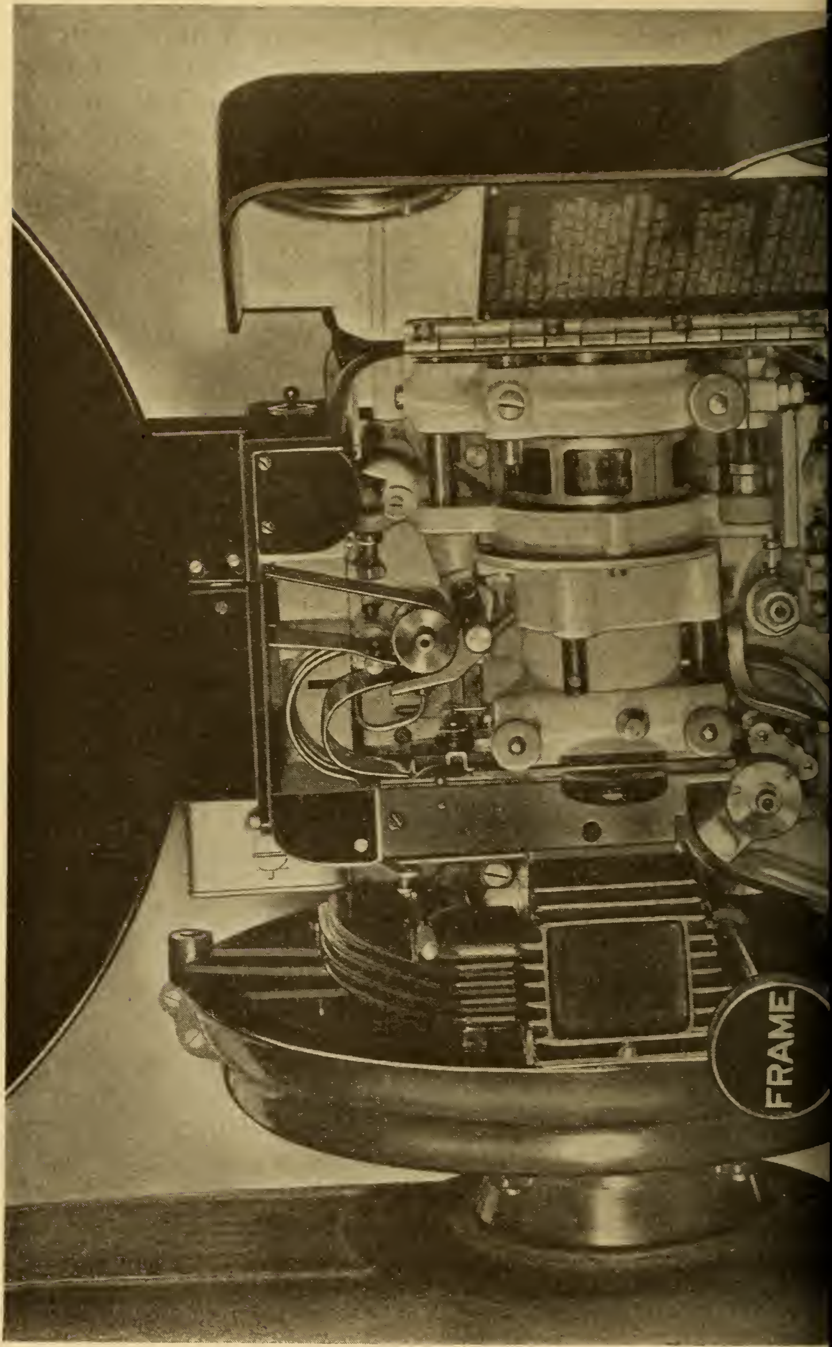
Film Reels for Shipment

(59) To protect film while in transit reels must be used that will not bend out of shape easily. Wire reels are excellent in this respect. They are neither rough nor sharply pointed anywhere and do not damage the film. Such reels must also be quickly attachable and detachable with respect to the magazine shaft locking device, and exceptionally strong where they engage it. They must permit the film to be attached to the hub easily and allow it to pull loose easily. They should be as light in weight as is consistent with strength and rigidity.

Projection Room Reels

(60) Each exhibitor should provide a full set of reels to be used in the theatre only during projection. These may be substituted for the exchange reels either when the film is being examined before projection or during projection. Film can be rewound on their shipping reels either during the last projection or when rewinding for shipment after the last projection.

Projection room reels should be kept in good condi-


FRAME

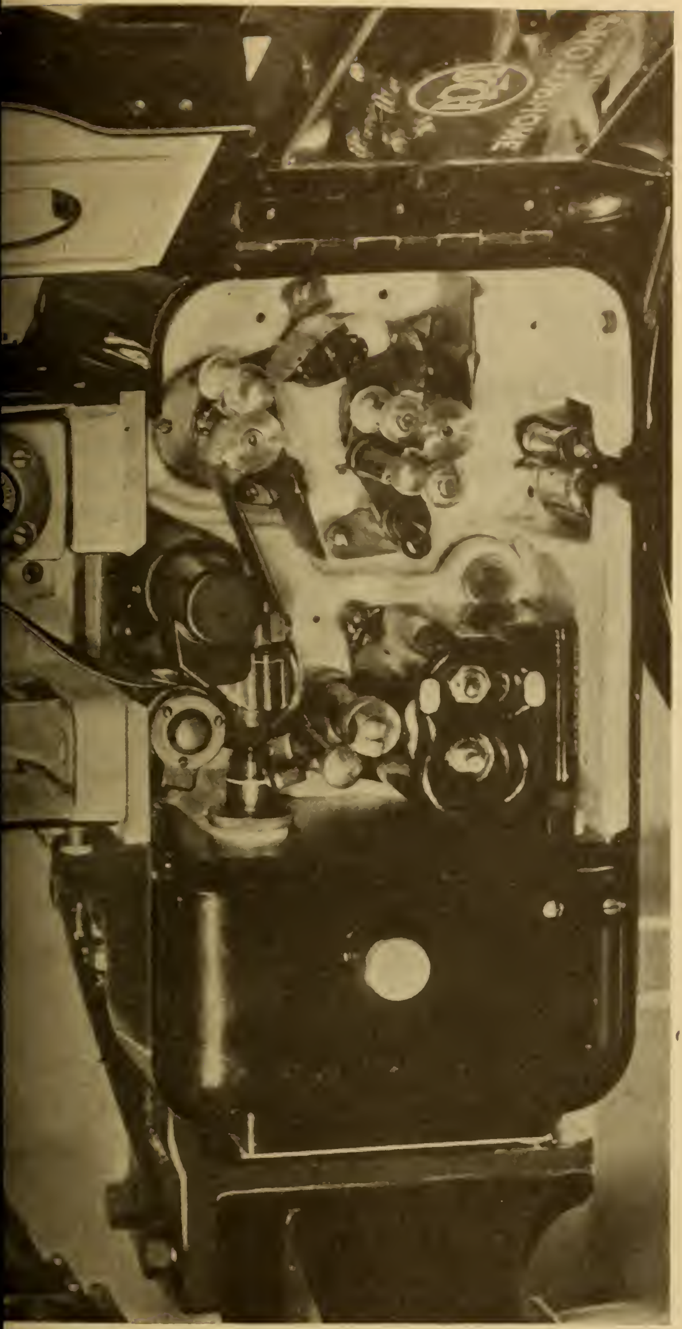


FIGURE 123

tion and repaired or replaced at the slightest sign of imperfection. No conscientious projectionist, unless he were compelled by conditions or an indifferent manager, would use crooked or damaged reels, risking injury to prints. It is wise to stamp all theatre reels with the name of the theatre and to guard against sending them to the exchange by mistake.

How to Estimate Footage in a Film Roll

(61) How may the footage in a roll of film be estimated?

Because film varies between 55/10,000 and 60/10,000 of an inch in thickness and because the tightness of the winding varies in different rolls of film, it is possible to calculate the footage contained in any roll with only approximate accuracy. However, it may be estimated as follows, using inches for all measurements: (62) First add the circumference of the opening (reel hub) in the center to the outer circumference of the film roll. Divide by 2. This will give the average length, in inches, of layers of film in the roll. Next, measure from outer to inner diameter of the film roll and divide by 5¾ (a compromise between the film thickness of 55/10,000 and 60/10,000 of an inch). Result will be the approximate number of layers of film in the roll. Multiply this by the average length of the layers and divide by 12 to get the number of feet. Final results will be footage of film in the roll as nearly as it can be arrived at by computation.

Measuring Film Accurately

(63) To measure the length of a reel of film accurately count the rotations of the projector mechanism crank shaft. Exactly one foot of film is passed with each rotation. Film measuring devices may be purchased from supply dealers.

Removal of Emulsion

(64) To remove the emulsion from the film, first soak it in a bucket of warm water to which has been

added all the ordinary washing soda it will absorb. Let the film soak until the emulsion has become soft, after which it may be washed or rubbed off. Afterward rinse the film thoroughly in clean, warm water. Soaking for a long time, over night, for example, will do no harm.

Cleaning Film

(65) Film may be cleaned with a soft cloth saturated with commercially pure carbon tetrachloride. Be careful not to scratch the film. The carbon tetrachloride must evaporate thoroughly before the film is rewound. If this is not done, the tetrachloride will bleach the emulsion away.

(66) Film is often cleaned with gasoline or benzine, but for several reasons we do not advise it. For one thing the film will curl badly. It may be harmed in other ways. As a rule it is best to leave the responsibility for cleaning the film to the exchanges where it should be done. They have the proper equipment and the staff to do it properly. The theatre should insist on receiving clean film from the exchanges.

Rain

(67) The effect termed "rain," which appears on the screen when old film is used, is caused by scratches in the film emulsion that have filled with dirt and thus have become more or less opaque.

The projectionist himself should object to receiving oil-smeared film from an exchange. It is right that he should do so, but he must remember that the oil got there in the first place either through the carelessness of some projectionist somewhere or by the refusal of a theatre management to make necessary projection equipment repairs.

(68) Some projectors have a slight oil leakage from the intermittent oil well. Unless the projector parts are badly worn and need immediate replacement, the projectionist, by exercising a little care, can keep the oil from reaching the film. It is generally done by a wiper located between intermittent sprocket and the oil well. It is not

an easy thing to set up, but many projectionists have done it successfully.

Standard Release Print

(69) The change-over cue in standard release prints consists of a black dot printed in the upper right hand corner of four consecutive frames of every print, the first of which is located 22 frames from the end of the picture—provided no frames beyond it have been eliminated in doubling up or in making a splice. On light backgrounds the black dot serves, but on dark backgrounds the black dot is or should be surrounded by a thin white line in order to make it more visible.

(70) In locating the change-over cue 22 frames from the end it was assumed that approximately one-half second would be consumed in operating the dowser when the cue showed up on the screen. If the change-over is to be perfect it is essential that there be no delay. The projectionist must act instantly when the cue appears on the screen.

(71) The projectionist may help himself to spot the cue marks by setting up a pad of paper near the observation port and during the first projection of the day make note on it of the action just preceding the cue in each reel. "Girl approaches well," is note enough to enable the projectionist to locate the cue mark for an exact change-over.

The Motor Cue

(72) The cue to start the idle projector motor consists of a black dot exactly the same as the change-over cue, printed on the upper right hand corner of four consecutive frames, the first of which is twelve feet and six frames from the end of the picture. (73) This distance enables the projectionist to make due allowance for variable speed of pick-up in different motors. The slowest may use almost the whole distance between the motor and the change-over cue marks. Every projectionist should test his motors and make the necessary allowance.

(74) Since the motor start cue is twelve feet and six frames from the end of picture, at 90 feet per minute this would consume approximately eight seconds of time. The problem is to ascertain just how many feet of film each motor, starting from dead position, will pick up in eight seconds, since that will be the actual motor-start footage for that particular projector, and must be considered when threading up. In other words, if the first projector picks up in eight feet, you must thread with the motor-start frame four feet and six frames past the aperture. If projector No. 2 only picks up twelve feet and six frames in the same interval, then you must place the motor-start frame over the aperture.

To Ascertain Motor-Start Footage

(75) In an empty theatre, place the footage frame marked No. 11 over the aperture. With one projector working, start the other the instant the motor-start cue appears. Operate the dowser the instant the change-over cue comes through. Should there be a lapse on the screen between the two reels, try again, this time placing frame No. 10 over the aperture; continue the operation until you have found at exactly what point the effect is perfect. This indicates exactly what frame to place over the aperture each time you thread that particular projector.

To avoid error by the relief men it is best to record the pick-up data on a couple of gummed stickers in some visible spot on each projector mechanism.

(76) Motor pick-up speed must be rechecked from time to time as it will alter with changing conditions, wear, etc., in the projector and soundhead. Rechecking is necessary, for example, after each overhauling of the projector.

(77) The process must be repeated for each motion picture projector you have, since there may be decided variations in pick-up speed in projectors located side by side.

(78) To start close the switch of the idle projector motor when the motor cue appears. The instant the

change-over cue appears on the screen operate the dowser.

CHECKING SYNCHRONISM

(79) The standard release may be used for checking synchronism. Any variation in the size of the loop between the projector and sound head aperture will destroy synchronism.

When the start-frame is threaded over the aperture and the loops are of correct length, there will be a diamond mark over the sound aperture. The diamond mark is located twenty frames in advance of the start-frame. (80) For perfect synchronism examine the location of the diamond mark at every threading. Turn the flywheel until the right motor-start frame is over the aperture. Experience will enable the projectionist tc judge the loop size very accurately.

UPKEEP OF STANDARD RELEASE PRINT

(81) Projectionists who take pride and interest in their work will do nothing to diminish the effectiveness of the standard release print. Every frame cut away for one reason or another reduces its usefulness in the projection room. With the general use of the 2,000-foot reel there will be little occasion to manhandle the release print. Remember that it is 100 per cent effective only so long as it remains in its original condition and occupies its original position with relation to the beginning and end of the reels.

STANDARD 2000-FOOT REEL SPECIFICATIONS

The essential specifications given for the standard 2000-foot reel approved by the Research Council of the Academy of Motion Picture Arts and Sciences, and adopted as of September 1, 1936, are as follows:

Outside diameter,, 14½ inches. Hub diameter, 4 inches. Free inside width, 1½ inches. Flanges (sides) must be of No. 24 gauge (0.25-inch). Hub must be of No. 20 USS (0.0375-inch) gauge. Rib heights shall

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not be less than ⅛-inch, except that a somewhat thinner metal may be used if ribs are of such nature as will insure equivalent stiffness. All metal edges must be rolled and flattened. (Full specifications may be obtained upon application to the Research Council, Academy of Motion Picture Arts and Sciences, 1217 Taft Building, Hollywood, Calif.)

THE MOTION PICTURE PROJECTOR

Practical Questions

(For answer to each question see statement of corresponding number in Chapter XII)

1. Name the four basic components of a motion picture projector.
2. What is the most important requirement of a projector pedestal?
3. Must the supporting floor be without movement or vibration?
4. How should the supporting stand be secured to the floor?
5. How should anchor bolts be embedded in a cement floor?
6. What adjusting facility may the supporting base provide for the projector mechanism?
7. What adjustments must the tables carrying lamphouse and mechanism provide?
8. What fault in the screen image does the audience discern if the pedestal is out of level sidewise?
9. Describe a modern type projector pedestal.
10. How many of the photographs on a modern motion picture film are projected each second?
11. How are the film sprocket holes held in the teeth of the upper sprocket?
12. How are the film sprocket holes held in the teeth of the other sprockets?
13. What device forces the lower magazine reel to wind up the film?
14. What is exceptional about the way the intermittent sprocket revolves?
15. Briefly, what does the shutter do?
16. State the conditions under which projected photographs can give the illusion of moving pictures.

THREADING THE FILM, PAGE 289

17. What is meant by threading the film?

THE TAKE-UP, PAGE 289

18. Explain why the reel in the lower magazine must be clutch-driven.
19. Describe one simple form of take-up.

FRAMING THE PICTURE, PAGE 290

20. What is meant by framing the picture?
21. Explain how the film is positioned in the "gate."

SHUTTERS, PAGE 292

22. Describe the Brenkert projector shutters.

STRIPPERS, PAGE 292

23. What is a stripper? What is its function?

DRIVING ARRANGEMENTS, PAGE 293

24. Describe in outline the driving arrangements of the Simplex E-7 mechanism.
25. Describe in outline the driving arrangements of the De Vry mechanism.
26. How are the driving gears of the Brenkert mechanism lubricated?
27. How are the bearings of the Century projector lubricated?

THE INTERMITTENT MOVEMENT, PAGE 295

28. What part of a projector is sometimes called the "heart" of the mechanism?
29. How are the rotating shutter and intermittent movement locked together to work in exact synchronism?
30. What is accomplished by each cycle of action of the intermittent movement?
31. At 90 feet per minute projection speed how often is the projector aperture covered with a film photograph?
32. How accurate must the action of an intermittent movement be?

33. How closely are intermittent parts fitted together?
34. What parts make up the standard intermittent movement?
35. Explain the action of an intermittent movement.
36. What is meant by an intermittent movement being "on the lock"?
37. Is the speed of the intermittent sprocket unvarying from time of starting to time of stopping?
38. By what process are intermittent parts finished?
39. What parts of modern intermittent movements are hardened? Why are intermittent sprockets no longer hardened?
40. How is any inaccuracy in the intermittent movement that effects the intermittent sprocket magnified on the screen?

Intermittent Movement Lubrication, page 299

41. What is required to keep the intermittent movement properly lubricated?
42. How is the time for draining oil wells determined?

Intermittent Sprocket, page 299

43. What is the accepted speed of intermittent action?
44. How fast is film fed down to and taken away from the intermittent sprocket?
45. How is the intermittent action of the film made possible?
46. Describe the action of the upper and lower loops and the film as a whole.
47. How often and in what manner should the intermittent sprocket teeth be examined?

Lost Motion in Intermittent Sprocket, page 302

48. How closely must the cam be adjusted to the star?
49. What is the test for correct adjustment between star and cam?

Replacement of Intermittent Sprocket, page 302

50. What happens if the sprocket is too tight or too loose upon its shaft?

51. How does the projectionist proceed to install an intermittent sprocket?
52. Describe the correct procedure in installing a new sprocket on a shaft.
53. How can a V block be made?

Aperture Tension, page 303

54. What is the effect of insufficient tension at the aperture?
55. What is the effect of too much tension at the aperture?
56. What tension at the aperture imposes the least strain upon both the film and projector mechanism?
57. Describe a practical method of adjusting tension at the aperture without resorting to special tools.
58. How do you determine whether or not the tension shoes on each side are exerting the same pressure?
59. Why does good definition require that the surfaces of the tension shoes and the aperture plate tracks be perfectly level and flat?
60. Will worn tension shoes and aperture plate tracks curve the film as it lies over the aperture?
61. How often should tension shoes or aperture plate tracks be tested for flatness?
62. What must be guarded against in installing new aperture plate tracks (or a plate and tracks in one unit)?

The Rotating Shutter, page 307

63. What is "persistence of vision"?
64. What is the only thing that is visible to the eye on a motion picture screen?
65. What would happen were a picture projected without the rotating shutter?
66. Does the shutter master blade cut all light from the screen when the film is moving over the aperture?
67. Why has the rotating shutter more than one blade?
68. Explain the illusion of continuity of motion.

Setting the Shutter, page 309

69. Describe the process of setting a shutter.

Rotating Shutter and Intermittent Speed, page 309

70. What is the relation between the speed of the intermittent movement and the width of the shutter master blade?
71. What is the relation between intermittent speed and the light that is allowed to pass by the rotating shutter?
72. What are the limiting factors in intermittent speed?

The Modern Rotating Shutter, page 310

73. Did the old type of rotating shutter have any effect on the heat applied to the film?
74. Does the modern type rear shutter have any effect on the heat applied to the film?

The Disc Type Rear Shutter, page 311

75. How far is the rear shutter located from the aperture?
76. What is the relation of the rotary speed of the master blade edges to the distance between the shutter shaft and the center of the light beam?
77. Though the time interval of cutting the beam is short why is its effect considerable?
78. May either blade of most disc type rear shutters be used as the master blade?
79. Do rear shutters create an air current at the aperture and thereby reduce aperture temperature?

The Horizontal, Cylindrical Type Shutter, page 312

80. Describe the horizontal cylinder type rotating shutter.
81. Describe the location and housing of the horizontal, cylindrical type shutter.
82. Why does the ratio between width and speed of the disc type shutter blades not apply to the Motiograph shutter?
83. Does either blade of the Motiograph shutter act as both, master and cut-off blade?
84. Describe the double shutter of the Simplex E-7 projector.
85. How is it these shutters rotate in the same direction, yet have the effect of rotating in opposite directions?

REGULATING THE FRONT SHUTTER, PAGE 314

86. What is meant by "point of aerial image"?
87. Is it important that front shutters be located at the point of aerial image?
88. What effect does the blade produce at the point of aerial image?
89. Is there any advantage to be gained in locating the shutter at the point of aerial image unless the width of the shutter master blade is reduced?
90. Describe a practical method of testing the width of master blade.
91. If the width of the master blade is reduced is it necessary to reduce the width of the cut-off blade?

TRIMMING THE REAR SHUTTER BLADES, PAGE 316

92. In what two problems of the rear shutter is the projectionist most concerned?
93. In testing the width of the shutter blade what should be used?
94. How far do local conditions control the adjustment of the rear shutter blade?
95. How may beam depth at shutter position be ascertained?
96. What is meant by the "effective beam"?
97. How would you lay out the effective beam on paper?

THE GEAR TRAIN, PAGE 318

98. What functions does the gear train perform?
99. How much lost motion is permissible in a gear train?
100. What maximum amount of wear is permitted in the gear train?
101. How may lost motion in a gear train be measured?

GEAR LUBRICATION, PAGE 319

102. What is the best lubricant for projector gears?

LUBRICATION OF BEARINGS, PAGE 319

103. How much oil is necessary adequately to lubricate any projector bearing?

SPROCKET IDLERS, PAGE 320

104. What function do sprocket idlers perform? What two different elements are used to hold the film to the sprocket?
105. At what distance should idlers be spaced away from the face of the sprocket?
106. How are sprocket idlers spaced the correct distance from the face of the sprocket?
107. What may happen if the sprocket idler is too near or too far from the face of the sprocket?
108. Must the ends of sprocket idlers be equidistant from the face of sprocket? What happens if the distance is unequal?
109. What may happen if the sprocket idler rollers are not properly lubricated? How often should they be inspected?

UPPER MAGAZINE TENSION, PAGE 320

110. Why should tension be applied to the reel in the upper magazine of a projector? How should it be applied?

LOWER MAGAZINE OR TAKE-UP TENSION, PAGE 321

111. Why must slippage be provided for the lower reel?
112. How much tension should be applied to the slippage device?
113. Will too much take-up tension damage the film? Will it cause excessive wear of the lower (hold-back) sprocket?

MAGAZINE ROLLERS AND FIRE TRAP, PAGE 321

114. How often and for what purpose should the magazine rollers and the fire trap be inspected?
115. Should the magazine fire trap rollers be lubricated?

THE PATH OF FILM THROUGH THE PROJECTOR MECHANISM, PAGE 322

116. How often should the path of the film through the projector mechanism be inspected?

117. How often should the path be inspected when using new films?
118. How often should the aperture plate track and tension shoe bearing surface be inspected?
119. Is it essential that the film pass through the projector mechanism in a perfectly straight line?
120. By what means is the film guided past the aperture?
121. How may the straightness of the film path be judged? What rule should be observed if it is necessary to install a new lateral guide roller?

AUTOMATIC FIRE SHUTTER, PAGE 323

122. Of what does an automatic fire shutter consist?
123. Are all fire shutter mechanisms the same? What care do they require?
124. At what minimum projection speed should the fire shutter rise and fall?
125. How often should the operation of the fire shutter be checked?
126. What length of film suffices for the loop movement?
127. How may the required loop size be judged?
128. What items should have especial attention and consideration in the care and operation of the projector?

MANUFACTURERS' INSTRUCTIONS, PAGE 324

129. Where can detailed instructions concerning a particular make and model of projector be found?
130. Cite some points of detail covered in manufacturers' ininstruction books.

TRAVEL GHOST AND RAIN, PAGE 325

131. What is travel ghost? What conditions cause it, and how are those conditions corrected?
132. What is "rain"? What causes it? How can it be prevented?

CHAPTER XII.

THE MOTION PICTURE PROJECTOR

(1) A motion picture projector consists basically of four parts: (a) a pedestal or support; (b) a lamphouse, or source of the projection light; (c) a soundhead, the function of which is discussed elsewhere in this book, and (d) a projector head, also called the projector mechanism, which is subject of the present chapter.

(2) A word, however, is needed concerning the pedestal on which the other thee parts are mounted. This must be of sufficient strength and rigidity to hold them without vibration. Its contact with the floor must have sufficient area to assure this condition, assuming the floor itself to be without movement or vibration. In considering the projector support it must be remembered that any vibration of the mechanism backward and forward upon its base will be magnified many times upon the screen, the magnification being proportionate to the distance between lens and screen.

(3) Because absolute rigidity is required, the floor itself must be without vibration and the projector supporting stand must contact it securely by means of anchor bolts.

(4) When building a new floor, the kind and model of projector should be decided upon in advance, a template made and the anchor bolts suspended therein, with heads not less than four inches below the floor surface. The concrete is then carefully and solidly packed around them, forming an ideal anchorage for the projectors.

(5) It is possible to embed anchor bolts in a cement floor that is already laid. Drill holes four inches deep and of sufficient diameter just to admit the heads of the anchor bolts, which need only be one-eighth inch larger than the bolts themselves. Then, with a small, round-

nose or diamond point cold chisel, cut small holes around the sides of the bolt holes or roughen their sides by gouging out pieces of concrete. This helps the metal filling to be well anchored.

Next set the anchor bolts in place, heads to the bottom, and fill the space around them with molten lead or babbitt.

(6) The supporting base may have an up-and-down adjustment with a proper locking device, for raising or lowering the projector mechanism. (7) Means must be provided by which the table which supports the lamphouse and mechanism may be tilted and locked rigidly in position to provide an upward projection angle of not less than 10 degrees and a downward angle of not less than 25 degrees. Greater projection angles are used, but it is poor practice.

In the supporting base of the pedestal type, provision should be made for carrying the various circuit wires upward through the supporting column. It is not essential, but makes a neater job.

(8) The projector must be set perfectly level sidewise. else the screen image will be out of level.

(9) Fig. 124 illustrates a modern type of pedestal. The sloping platform supports the lamphouse —the source of projection light — which is bolted to that platform. The projector mechanism and soundhead are bolted to the member that protrudes at the right top of the illustration. Provisions are included in the sloping platform whereby the lamphouse mounted thereon can be shifted forward and back or left and right or both, to

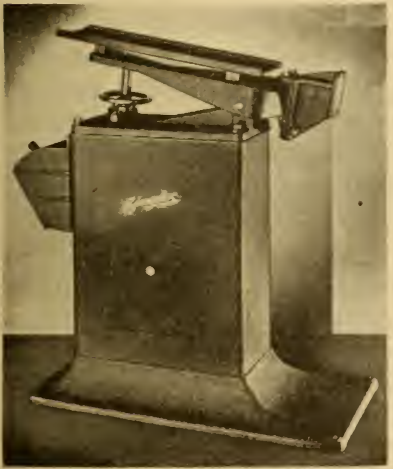

FIGURE 124

align it exactly with the projector head. When this has been accomoplished the lamphouse is firmly locked in place on the sloping platform. The slope of the platform can be altered by the hand wheel seen the left, top, of the pedestal, and the adjustment of this wheel can also be firmly locked. When the tilt of the lamphouse platform is changed, by means of the hand wheel, the angle of the protruding member to which the projector mechanism is mounted also changes, keeping lamphouse and mechanism in perfect alignment. The protrusion at the left of the pedestal is the casing of the switch which controls the current to the light source. The pedestal is hollow, and in modern installations conceals and shields electrical wiring, which is brought up through the floor. This wiring can be reached by pulling out the removable panel, visible in the photograph some little distance below the trade mark.

(10) To understand the principle of action of the projector mechanism it is necessary to be very clear about the mechanical requirements of motion picture projection. A reel of theatre-type film contains 12 separate photographs for each 9 inches of its length. These photograph vary in shading from transparent to completely black. Each of them must be interposed briefly between a source of brilliant light and the screen on which the audience views the picture. When this is done the light streams through the photograph and with the help of proper lenses is focussed upon the screen, presenting an enlarged duplicate of that photograph before the audience. Twenty-four of these photographs are projected before the audience each second to produce the illusion of motion.

(11) As much as 2,000 feet of film, wound on a metal reel, is placed in the upper magazine of the mechanism. The lower edge of that magazine can be seen in Fig. 125. The reel in the upper magazine is free to spin on an axle provided for it, thus permitting the film to be unwound. A few feet of it are unwound, and "threaded" into the mechanism, as will be explained later. Fig. 125 shows film properly threaded. Let us trace the path of the film

from the top of the projector downward. It passes the upper sprocket, a toothed wheel, the teeth of which engage the perforations at the sides of the film. The film is held in engagement with the sprocket teeth by the sprocket idler—the smaller wheel shown in contact with the lower left-hand side of the sprocket. To the left of the upper sprocket there is a loose loop in the film, after which the celluloid passes through the "gate" and "aperture". There its edges are held under carefully adjusted tension by polished metal plates, between which the moving film slides.

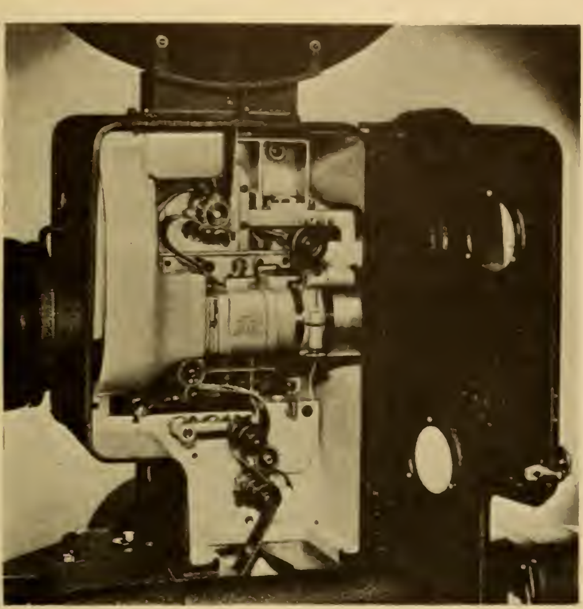

FIGURE 125

(12) Light comes from the left of Fig. 125, shines through the film, and into the projection lens, the white casing of which is seen just right of the gate. Below the gate the film perforations are engaged by the teeth of the intermittent sprocket, against which they are held by the intermittent idler, shown directly below the intermittent sprocket. Sometimes the place of the intermittent idler is taken by an intermittent "shoe." There is

another lose loop in the film, below and to the right of the intermittent sprocket; beyond this loop the perforations are engaged by the lower or "take-up" sprocket. Below this again the film passes over a "pad roller"—a free running rotating member without sprocket teeth, and then enters the soundhead at the bottom of the illustration.

(13) In the soundhead there are other sprockets moving the film downward, and below the soundhead it enters the lower magazine where it is wound up on another reel. The lower magazine is much like the upper magazine, with one exception. The spindle on which the wire reel is mounted cannot be free-running, it must be forced to rotate so the reel will wind up the film as it moves down from the soundhead. The spindle is made to rotate by a device known as the "take-up."

(14) The take-up, the three sprockets in the projector mechanism, and whatever sprockets there are in the soundhead, all are mechanically linked to, and thus driven by, the projector motor, a portion of which can be seen at the extreme lower right of Fig. 125. The upper and lower sprockets of the illustration, and all the soundhead sprockets, revolve in unison. The intermittent sprocket does not. It revolves intermittently—start-and-stop, start-and-stop—stopping 24 times a second. The mechanical arrangements that secure this result will be explained shortly.

(15) While the intermittent sprocket is in motion a shutter, not clearly shown in this illustration, intercepts the light beam. Otherwise the picture on the screen would be blurred. When the intermittent sprocket stops, the photograph before the aperture at that moment becomes motionless; then the shutter moves out of the way and allows light to shine through that photograph to the screen, projecting one photograph.

(16) When as many as 24 photographs per second are projected in this way, sandwiched by intervals of darkness; and when any object occupies a slightly different position in each successive photograph, an optical illusion is produced whereby the object appears to be moving.

This is the secret of moving pictures. The intervals of darkness are not seen by the audience; the screen appears to be continuously illuminated.

THREADING THE FILM

(17) In every mechanism there is some provision whereby the idlers can be pushed back or hinged back from the sprockets, and the "gate" can be opened, so that the projectionist (having pulled down a few feet of film from the upper magazine) can insert the celluloid between each sprocket and its idler, and between the polished steel tension pads and runners of the gate. As he sets the film properly at each sprocket, accurately engaging the perforations with the sprocket teeth, the projectionist snaps the idler back into position to hold the film; as he sets it properly in the gate, he snaps the gate closed. He takes care to leave the correct length of loop or slack above the gate and below the intermittent sprocket, and he makes sure that one photograph is squarely framed in the aperture, not parts of two photographs. This entire process is called threading the film.

THE TAKE-UP

(18) The process of threading includes engaging a few inches of film on the hub of the reel in the lower magazine. When the motor is started, and film begins running downward through the projector, the reel in the lower magazine revolves, driven by the take-up, and begins winding up the film. Now the hub of the reel may be—to take an even figure—nine inches around; and as the speed of the film through the projector is 18 inches per second, the hub will have to revolve twice in one second, to take up 18 inches of film. But as more and more film is wound up on the reel, adding to the size of the "hub", a time will come when the "hub", including film already reeled up, is 18 inches around, and the lower reel then will have to revolve once per second. In other words, the speed of the lower reel must be variable, not constant, and therefore it cannot be driven by a simple

mechanical connection with the driving motor. It is driven by the take-up, which is a clutch.

(19) In one simple form the take-up consists of two fibre or leather discs. One is driven by the projector motor, usually through a bicycle chain connection; this in turn drives the other disc by simple friction, and the other disc drives the reel in the lower magazine. There is a certain amount of slippage between the two discs, which permits the reel to run slower whenever the film, coming down at only 18 inches per second, tends to hold it back. The amount of slippage between the two discs can be controlled by altering the pressure that forces them together.

Framing the Picture

(20) Fig. 126 is another type of Simplex projector, with film in the process of being threaded. The gate, it will be noted, is open—it is held open through the pressure exerted on a lever by the projectionist's right thumb. A portion of the interior of the soundhead is shown at the bottom of the photograph. Above the projectionist's right wrist is a knob marked "Frame". If through any flaw in the performance of the mechanism or any error in splices in the film, parts of two pictures appear in the aperture, instead of one being completely framed therein, the framing knob is manipulated to correct the condition. In the model here shown, the framing device acts upon the intermittent sprocket; in other

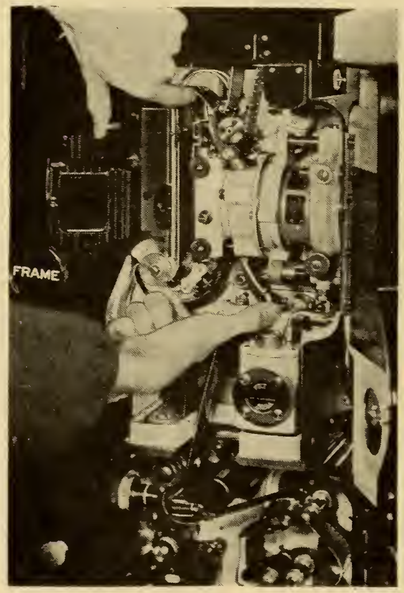

Figure 126

models it may operate to lengthen or shorten the path of the film through the mechanism by the necessary fraction of an inch.

(21) Fig. 127 illustrates (disassembled) the gate of the Brenkert projector. To the left are the film tracks, in the center, the pressure pads. When the gate is closed, the pressure pads face the tracks and press the film firmly against them. The pads are actuated by spring tension. This tension must be accurately maintained. Too little will not hold the film firmly enough; will allow it to shift slightly away from the tracks and out of the plane of exact focus. A shift of this kind amounting to a minute fraction of an inch will cause loss of sharp focus on the screen. Too much pad pressure, on the other hand, will tend to bind the film, increasing the strain on the moving parts of the mechanism, and may possibly cause the film to tear. At the right of Fig. 127 is the opposite or rear view of the center portion of that illustration. The circular opening that fits against the projection lens. In the left-hand portion of the figure, low down, is seen the aperture, with its removable aperture plate, and, some distance above, the "framing" aperture. The last is a feature of this projector. If the film is in frame in the framing aperture, it will be in frame in the projection

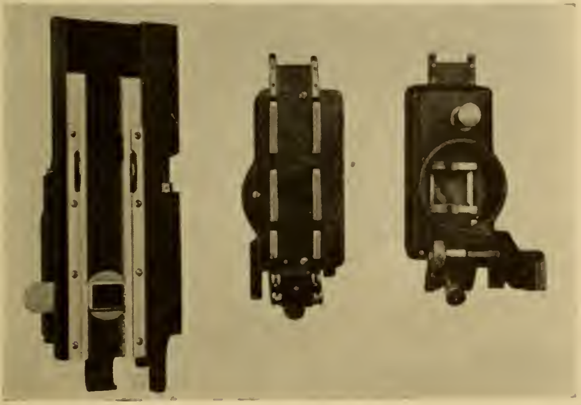

FIGURE 127

aperture. The projection aperture cannot be seen when the gate is closed, but the framing aperture can, being above the gate; thus the projectionist can assure himself that he has threaded his film in frame without having to open the gate to see.

SHUTTERS

(22) Fig. 128 is another view of the Brenkert mechanism, partly disassembled to show the two shutters. These shutters move in opposite directions, cutting off the light beam from both top and bottom. The aperture is beyond the rectangular opening seen right of the shutters and in line with the thick black tube of the projection lens holder. The small lamp bulb casts light through the framing aperture. Other types of shutters are illustrated and described further on.

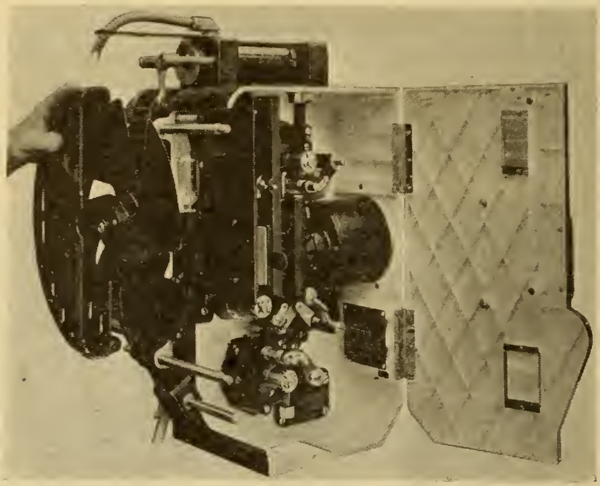

FIGURE 128

STRIPPERS

(23) Film is not pictured as threaded to the upper sprocket in Fig. 128. What appears to be film is a stripper. A stripper rests on the hub of the sprocket, where it does not interfere with the film. But when film tears, it

has a tendency to wrap itself around a sprocket. The stripper prevents this, forcing the film off, and keeping it from damaging itself against the sprocket teeth.

(24) Fig. 129 shows the gear or driving side of the mechanism illustrated in Fig. 126. Power is transmitted from the motor to the soundhead, and from a soundhead gear, the top of which can just be seen at lower left, to the gears of this mechanism. (A"shock-proof" gear, included in all more recent models of this projector—the Simplex E-7—is not shown in the drawing.) The larger of the lower gears drives the lower sprocket. The large gear just above this drives the intermittent movement (to be described hereafter) which in turn drives the intermittent sprocket. The upper sprocket is driven by a smaller gear, shown in mesh with a spiral gear mounted on an obliquely vertical shaft. The horizontal gear in the center of the picture drives the shutter shaft. The thin metal tubing (some of which can be seen between the oblique gear and the shutter gear) is part of the oiling system. By pressing a lever at the operating side of this mechanism (Fig. 126) the projectionist forces oil under pressure through these small tubes, which deliver it to each shaft in precisely the correct quantity and perfectly clean because it is filtered under pressure.

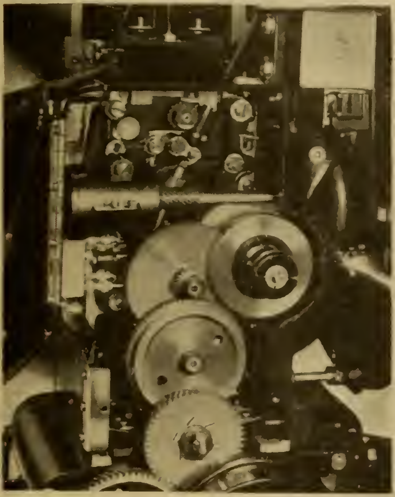

FIGURE 129

(25) Fig. 130 shows the driving side of the DeVry projector, in which gears are to a large extent replaced by sprocket chains. The chain leading obliquely downward toward the bottom of the drawing is driving the take-up. Fig. 131 is the operating or film side of the

same projector, which incorporates a built-in soundhead. The sprocket at the lower right of the picture is a soundhead sprocket; the lower sprocket of the projector proper is the one just above and left of the trade mark. This projector also is equipped with a framing aperture, the small lamp bulb for which is shown at top, left. The driving motor is inside the casing, at lower left.

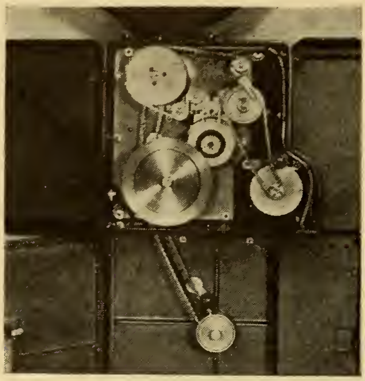
FIGURE 130

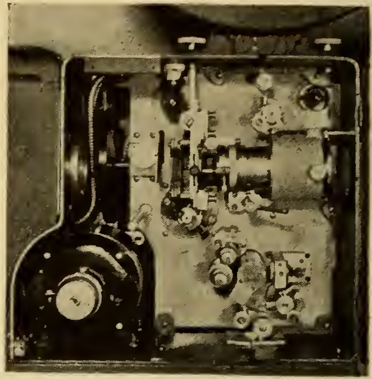
FIGURE 131

(26) Fig. 132 gives a glimpse, through glass, of the driving side of the Brenkert projector. The gears there seen are enclosed in an oil-tight casing with a glass window. They operate in a bath of splashing oil, and need no specific attention to lubrication. The projectionist merely sees that the oil reservoir is filled to the proper height. When at intervals even the large quantity of oil used by this mechanism does become contaminated with foreign matter the projectionist

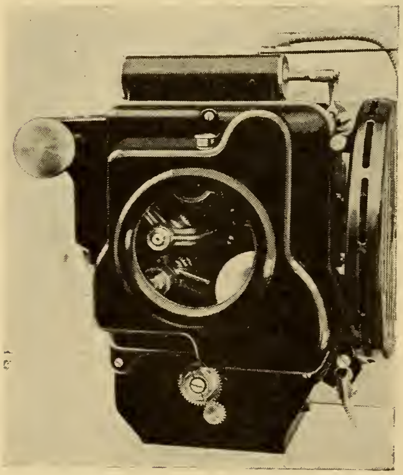
FIGURE 132

merely drains it out and re-fills the reservoir. The gear arrangement seen below the window includes a mechanical "fuse." If binding of the film, a poor patch or any other condition threatens to bind up the mechanism or strip any of its gears, a thin pin (not clearly seen in the illustration) will break, cutting off the mechanical connection of the driving motor. The projectionist locates and cures the difficulty, and replaces the mechanical fuse.

(27) Fig. 133 shows the driving side of the Century projector. The horizontal shaft is the shutter shaft. The gears through which the vertical shaft drives the lower sprocket, intermittent movement and upper sprocket are clearly seen. These shafts rotate on ball-bearings. The picture represents the Century single-shutter model; the double-shutter Century has very nearly the same appearance. Lubrication is largely taken care of by the fact that the ball bearings are of the self-lubricating type—that is, sealed in for life with a proper supply of lubricant which no dirt can reach to contaminate.

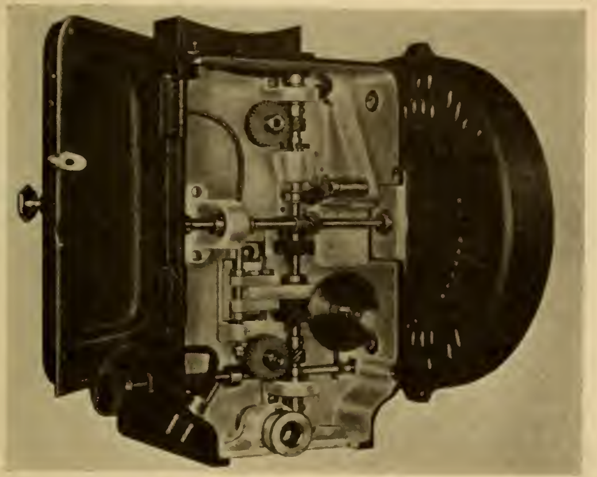

Figure 133

The Intermittent Movement

(28) The means by which the intermittent sprocket is made to operate with a stop-start, stop-start motion has

not yet been described. The intermittent is often called the "heart" of the projector mechanism. In all theatre-type projectors built today the intermittent movement is the same in principal and in general type of construction. Differences between various makes and models of intermittents are matters of refinement of design and accuracy of manufacture.

(29) The intermittent movement and the rotating shutter are so locked together by a train of gears that the shutter must rotate in exact synchronism, when the intermittent movement acts and by so doing moves the intermittent sprocket precisely one-fourth of a revolution.

(30) This cycle of motion displaces one film photograph from the aperture and substitutes the next succeeding one, the whole cycle lasting one twenty-fourth of a second. (31) In other words, it occurs twenty-four times per second, during which each one of twenty-four photographs is successively projected to the screen. (32) The accuracy of the action makes certain that each photograph or "frame" will remain perfectly still and perfectly flat over the aperture during its period of projection, and will, within one ten-thousandth of an inch, occupy precisely the same position occupied by every other photograph of the series.

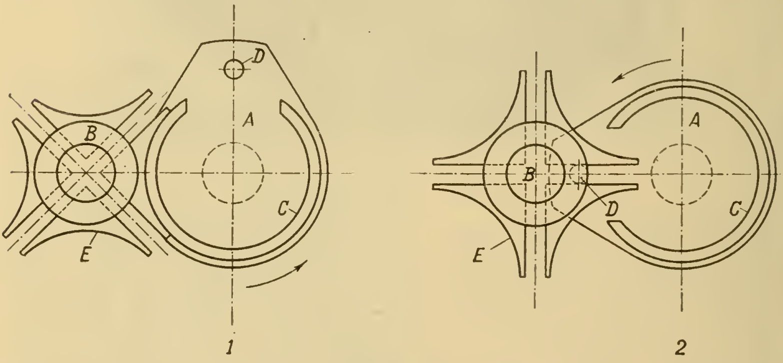

FIGURE 134

(33) To make the intermittent movement function with such extreme accuracy all vital parts are fitted

together with less than 1/10,000 of an inch tolerance of error.

In Fig. 134 we have two line drawings of a standard intermittent movement such as is now universally used in modern motion picture projectors. Incidentally, by means of a differently designed and constructed movement, the Powers intermittent performs precisely the same functions as does the standard type of Geneva movement, though Powers projectors are no longer widely used.

(34) Figures 134 and 135 illustrate the standard type of Geneva movement. It consists of a maltese cross of steel, B, commonly referred to as the "star," and steel cam A, upon which is mounted a master pin of steel, D, which drives the "star." This cam also carries a flat circular surface, C, by means of which the star, and therefore the intermittent sprocket which is mounted upon its shaft, are locked immovably while standing still—that is, in the interval the photograph is poised over the aperture and is being projected to the screen.

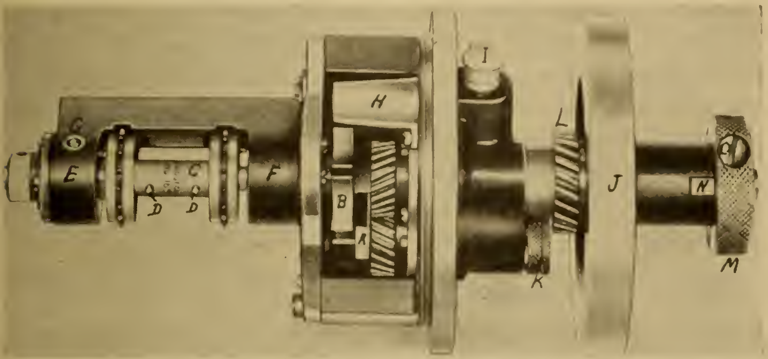

Figure 135

(35) The action is as follows: In part 1, Fig. 134, we see the two parts, cam A carrying the master pin D, which is in continuous rotation so long as the projector is in motion, and star B, which is standing still—one of its four curved surfaces E, being in contact with the surface

of cam ring C, in which position it is evident star B cannot be rotated. It must, in fact, remain perfectly still until the two surfaces are released. (36) In this condition the movement is said to be "on the lock."

Remembering that cam D rotates continuously in the direction indicated by the arrow, it is evident that presently pin D will engage with one of the slots in star B, and in that instant surfaces E and C will be out of contact and star B free to rotate under the control of pin D. Study the diagram and you will see how it works.

(37) As pin D enters the star slot it moves the star around. The movement is very rapid, but nevertheless by relation the star and its intermittent sprocket (mounted on its shaft) are started slowly and the speed gradually increased to maximum, which is about two or three times the normal 90 feet-per-minute movement of the continuously running film. The star and intermittent sprocket then slow gradually to a full stop, whereupon surfaces E and C re-engage, locking part B immovably. The picture is projected and the cycle of action is repeated.

CONSTRUCTIONAL DETAILS

All reputable manufacturers use only the very finest materials in constructing their intermittent movements. The shape and diameters of the sprockets and the dimensions and spacing of the sprocket teeth are all measured in ten-thousandths of an inch. Any sprockets, stars or cams failing to come within two ten-thousandths of an inch of the correct measurements are rejected.

(38) All intermittent parts are finished by carefully controlled, precisely accurate grinding processes. (39) In modern intermittent movements the cam and star are always hardened, but the intermittent sprockets sometimes are not because it was discovered that hardening causes undercutting in the form of a notch in the metal at the base of the sprocket teeth. Teeth not hardened wear off smoothly.

(40) Faulty functioning of the intermittent move-

ment will be magnified on the screen, in the form of an up-and-down movement, as many times as 0.600 is contained in the height, in inches, of the screen image, provided the trouble is due to faulty rotation of the intermittent sprocket. Any lateral (sidewise) movement of the intermittent sprocket will be magnified on the screen as many times as 0.825 is contained in the width, in inches, of the screen image.

Intermittent Lubrication

(41) Considering the foregoing it is obvious that such movements must be lubricated with carefully selected oil. Many theatre managers refuse to buy high grade oil, and then wonder why intermittent movements cost so much for repairs and replacements. It is best that projectionists use no oil in the intermittent movement oil well except that recommended by the manufacturer. Never use light household oils as they will bind up the intermittent movement quickly—and ruin it. The intermittent oil well should be drained and filled with fresh oil following each 100 hours of operation, but do not flush out the well with kerosene or other liquid. If you do, some portion of it will remain to impair the lubricating properties of the fresh oil. Filling up the oil wells periodically will not do. As oil is used its lubricating qualities gradually wear away and if it is mixed with fresh oil, the fresh oil loses its full strength. Draining at regular intervals is therefore essential. However, these instructions, which apply to most makes of projectors, do not apply to all. Check them against the instructions of the manufacturer of your mechanism.

(42) Dates for draining wells may be determined by dividing 100 by the number of hours the theatre operates per day. The answer is the number of days between drainings and refillings.

Intermittent Sprocket

The intermittent sprocket is part of the intermittent movement. (43) The interval during which the intermittent sprocket is at rest plus the time it is in movement is termed the "speed of intermittent movement." In present day "90 degree movements" the intermittent sprocket is at rest, with the film motionless over the aperture, three times as long as it is in motion.

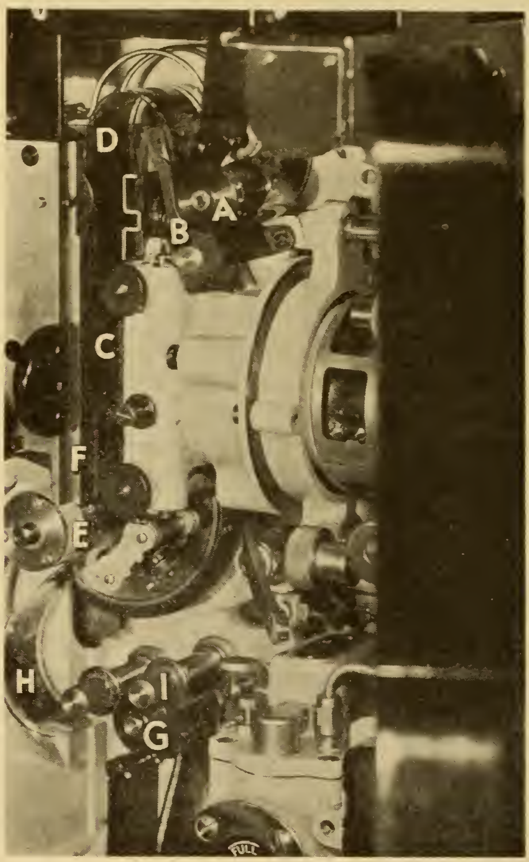

FIGURE 136

A quarter segment of a circle is 90 degrees. (A circle is divided into 360 degrees.) Pin D, in Fig. 134, is in engagement with the star slot and therefore moves the intermittent sprocket through exactly 90 degrees, but is disengaged for the rest of the circle or (360°-90°) 270 degrees.

Because the intermittent sprocket is in motion one-fourth of the complete intermittent cycle of action, the movement is a "three to one." The film lies over the aperture three times as long as it is in motion, though since the rotating shutter has two blades of equal width, the time of actual projection is reduced, approximately to half that time. In actual practice the period of projection is really a little more than that.

(44) The film is fed down to the aperture by upper sprocket A (Fig. 136) at a regular, unvarying rate of speed, namely, 90 feet per minute, or 18 inches per second. It is taken away by lower sprocket G, at the same rate of speed. Between these two sprockets it is moved intermittently by intermittent sprocket E—its total speed at this point being exactly equal to that of the film above and below sprocket E. (45) Now, this intermittent movement film action is made possible by upper loop D and lower loop H, which function to absorb the stoppage of the film between the steadily moving sprockets A and G. (46) While the film is stationary at aperture C, loop D becomes longer and loop H shorter, and since during each cycle of action by the intermittent sprocket exactly three-quarters of an inch of film is moved down over the aperture, exactly that length of film is fed to upper loop D by sprocket A and taken away from loop H by lower sprocket G. The compensation is equal and the action can continue indefinitely.

INSPECT SPROCKET TEETH

(47) The constant friction of film against metal wears the metal away. Worn intermittent sprocket teeth not only produce an unsteady picture but tear the film sprocket holes. Therefore the intermittent sprockets should be examined after each fifty hours of operation. Use a magnifying glass to discover the flaws that frequently cannot be seen by the naked eye. If there is any visible undercutting in the form of a small notch at the base of the working side of the teeth, the sprocket should be replaced at once. If no notch shows but the

teeth are appreciably reduced in width at their base, they are equally useless and harmful.

Lost Motion in Intermittent Sprocket

(48) Adjustment between cam A and star B (Figs. 134 and 135) must be accurate to prevent any independent motion of the intermittent sprocket. Test it by rocking it back and forth with your finger while the movement is on the lock. At the same time the adjustment must not be too close or it will have a tendency to bind when the projector mechanism flywheel is turned. (49) The adjustment is correct when the flywheel rotates freely and there is no lost rotary motion in the intermittent sprocket when the movement is on the lock—that is, when the locking ring C is engaged with one of the star quarter-circles E.

The intermittent movement may be adjusted either when the mechanism is hot or cold.

Replacement of Intermittent Sprocket

Relatively few projectionists are fully equipped with technical knowledge and experience requisite to satisfactory performance of this task. Moreover, with many projectors special tools are requisite if correct results are to be attained. Even the most minute inaccuracy in installation will result in unsteadiness of the screen image as a whole. (50) The screen image will be unsteady if the fit between the sprocket and shaft be either too loose or too snug. If too loose the whole sprocket will "wabble." If the sprocket be forced on too snugly, its rim may be strained and warped slightly out of true. In either case results will be much the same. Lastly, if there be any end-play in excess of that necessary to avoid undue friction, the star, cam, bearings and gear train will all be subjected to unnecessary strain by the friction thus engendered, and thus caused to wear much too rapidly.

(51) In most modern projectors changing the intermittent sprocket necessitates removal of the entire intermittent movement, instructions for doing which are sup-

plied by manufacturers. The sprocket arm is then removed. The utmost care is required to avoid contact of star with casing, or with anything else. It is machined to 1/10,000 of an inch accuracy. A wholly invisible abrasion or dent may and probably will produce faulty results.

The sprocket is joined rigidly to its shaft either by small taper pins or machine screws. Usually some type of "pin ejector" is used to remove the pins (See Fig. 137). The sprocket may usually be removed from the shaft by pulling with a twisting movement. If not, lay its hub (hub—not rim) on suitable hard-wood blocks laid across partly opened vise jaws and drive the shaft out by tapping gently on the shaft end, using a light hammer and hardwood punch. Do not use a metal punch of any sort, or permit the shaft to contact anything, however lightly.

(52) To install a new intermittent sprocket, first clean the shaft very thoroughly and blow strongly through the hole it is to enter. Do not, under any circumstances, attempt to wipe it out. Having the shaft clean, cover its entire surface with high grade oil. Shove the sprocket on the shaft with a gentle, twisting motion. If it sticks, remove, reclean the shaft, relubricate and try again. It may take several trials but patience must be exercised. Only the small fraction of 1/10,000 of an inch of metal must be worn away. In any event proceed gently. Don't attempt to rush matters by using too much force. In replacing taper pins or holding screws, set them up firmly, but not too much so, lest the sprocket be strained and its rim thus warped out of shape. A 1/10,000 inch fault here means a fault that may be visible on the screen.

(53) In the event you do not care to purchase the pin ejector, you can make a V block as shown in Fig. 137. If covered with vaseline and protected from rust it will last a lifetime.

APERTURE TENSION

(54) When there is too little tension the screen image

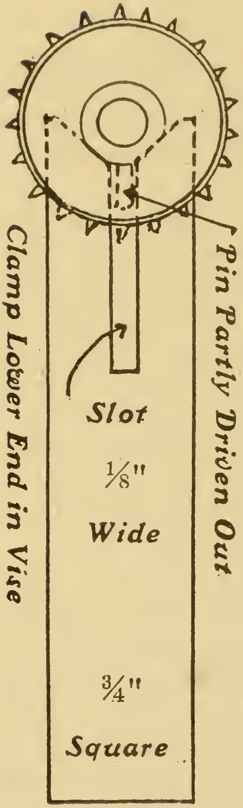

Figure 137

is unsteady. (55) Too much tension, on the other hand, imposes a great strain upon many parts of the intermittent mechanism, upon the delicate edges of the sprocket holes of the film, upon the motor that drives the projector, upon the projector gear train and consequently upon the shaft bearings which give the gears their support, and generally upon all working surfaces of the intermittent movement including the edges of the sprocket teeth and the tension shoes and aperture plate film tracks.

Even under the best of conditions the intermittent mechanism represents a sensitive adjustment of precisely accurate parts working at top speed under strain. Some sections of the intermittent assemblage must start, reach high speed and stop twenty-four times each second for long and continuous periods of time each day. This truly "nerve-wracking" action takes place against the braking effect of the aperture tension.

(56) If the tension applied at the gate is just enough to permit the film to stop perfectly still for a brief interval over the aperture (without unsteadiness or overshooting of the screen image), then the intermittent is accomplishing its work smoothly. But if the aperture tension is excessive, the actuating pin D in Fig. 134 will press against the side of the star slot with sufficient force to overcome the abnormal tension. It is obvious that the excessive tension at the aperture will, in time, destroy the delicate adjustment of the whole intermittent mechanism, which moves 1,440 times per minute.

Checking Aperture Tension

(57) One method of securing proper aperture ten-

sion, hence minimum wear of almost all parts of the projector mechanism and of working edges of film sprocket holes, is to reduce tension spring pressure until the screen image barely starts to become unsteady, followed by gradual pressure increase until the unsteadiness disappears. If drive motor speed can be varied, or the projector hand-cranked, so adjust tension that very slight unsteadiness in screen image appears when film speed is 100 feet per minute, which provides the minimum tension required at present standard ninety feet per minute projection speed. The projectionist should remember that excess tension imposes excess strain on the mechanism, hence excess repair and replacement costs which can easily be avoided by exercising ordinary care and judgment.

(58) Care must be exercised to prevent uneven tension where the tension is provided by two separate tension shoes, each with an independent spring. An ordinary, small postal scale will help to achieve the proper balance. First remove the letter pan. Arrange a block of wood under the two springs, so that each will strike it when pushed down a certain equal distance. Place the letter pan against the center of the shoe and press it down until it just misses contact with the wood. Note the scale reading and repeat the process on the other shoe. You will find this a reasonably accurate method of checking the tension of the two springs.

Flatness of Film Over Aperture

(59) If one conjugate foci point of the projection lens is the film and the other the screen surface, why must the film lie perfectly flat over the aperture?

One conjugate focus—that is, the optical center of the lens in relation to the film at the aperture—is very short as compared with the other—the optical center of the lens in relation to the screen—hence a very small change in its length will affect the front foci point considerably.

Suppose we now consider the surface of the film at the aperture as thousands of pinpoints, each of which is sending its quota of rays to its corresponding point on the screen—as is actually the fact. If the film lies perfectly flat (we disregard the fact that to make this hold perfectly true the screen must present a spherical surface the center of which would be the optical center of the projection lens) then all these thousands of conjugate foci points would be at exactly equal distances, hence all of them would focus equally well.

Suppose the film does not lie flat over the aperture. Instead it buckles in or out about 1/64th of an inch. Such a condition, it is readily seen, removes some rear conjugate foci points farther from the lens than others, and since a difference of 1/64 of an inch in the short end will make quite a lot of difference as to where the front, or long end will focus, it is evident the screen image will not be in sharp focus over its entire area. If the center is focused, the sides will be "out," and vice versa.

(60) Naturally when the surface of the tension shoes and aperture plate tracks become worn, the film will pass the aperture in curved form, not perfectly flat as it should. Parts of the picture will not be in sharp focus.

(61) After fifty hours of service which, particularly if heavy tension be used, may mean considerable wear of aperture plate tracks and tension shoes, test them, using a steel straightedge. Also carefully examine the lateral guides for possible grooving, which permits side movement of the film over the aperture. If there is visible wear, replace the parts with new ones immediately, else you may expect side movement of the screen image and/or intermittent out-of-focus effect proportionate to the amount of wear.

(62) When installing new aperture plate tracks, or a new aperture plate, if plate and track form one unit, make very sure that the surface that is to receive them is perfectly clean. A small deposit of dirt, almost invisible, may throw them out of true, perhaps by several thousandths of an inch. When the installation is completed test the surfaces of both tracks with a steel straight-edge.

WHY A SHUTTER IS NECESSARY

(63) The human eye has the ability to retain upon its retina the impression of any light incident thereon for a small fraction of a second after the light itself has vanished. This "persistence of vision" makes motion pictures possible.

Darkness is invisible, except as a contrast to light. (64) The light upon a screen surface is the only thing that is visible to or makes any impression upon the eye. Looking at a screen we see certain shades of light thereon, while at the same time certain portions of the screen surface are more or less invisible. It is the pattern formed by various shades of light that forms the screen image.

(65) If we were to remove the rotating shutter and project a reel of film, we would see very little picture. In its stead would be a series of more or less jumbled streaks of light. As the film moves across the aperture the transparent areas (light spots) move with it, and, with the shutter removed, the eye sees them move in the form of streaks of light. Due to persistence of vision, the bright spots in the picture will be impressed upon the eye while the film is at rest, and the eye will also see them while the film is in motion over the aperture, very largely obliterating the shadings that form the picture on the screen.

(66) It is obviously necessary to cut off all light from the screen while the film is in motion over the aperture,* and that is exactly what the master blade of the shutter does. Each time the intermittent sprocket comes to rest, the master blade moves away from in front, "opens the lens," permitting light to pass through.

We have cut the light off the screen while the film is in motion over the aperture, but to the eyes of the audience the fact is not apparent. Why this is so we shall presently explain.

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*It has been found that, without affecting the screen image, the lens may be about one-third open when the intermittent sprocket starts to move, and may be about the same distance open when the sprocket finally comes to rest, which of course adds to the total of screen illumination.

Every shutter has two blades. The one that covers the aperture while the film is in motion is called the master blade. The other, which covers the aperture for a short period of time while the film is at rest, is called the cut-off blade. If there is a double shutter, as is the case in many projectors, there is one master blade on each shutter —two master blades in all—and one cut-off blade on each shutter—two cut-off blades in all.

WHY THE SECOND BLADE

(67) As has been shown, it is essential that the light be cut off from the screen while the film is in motion over the aperture. That fact explains the master blade, but what is the purpose of the cut-off blade?

The science of optics has not yet given a completely satisfactory answer. The facts are that the periods of darkness must not be too long and the periods of light and darkness must be correct in length and of approximately equal duration in time. If we used but one shutter blade (the master blade) we would have a terrific flicker. If—when projecting 90 feet of film per minute —we add a second blade (called the cut-off blade) of approximately equal width with the master blade, and located at the opposite diameter from the master blade, so that periods of light and darkness are equally spaced and of approximately equal duration (in practice the light holds just a little longer than the dark intervals), all visible flicker will disappear. Not only that, but the impression of light from one period of illumination will carry over (persistence of vision) through each dark period, so that we shall have the *illusion* of constant screen illumination. (68) Moreover, the difference in position of the various moving objects in the picture will be so slight that they will blend together into another illusion, namely, that of continuous motion. Put into a different phraseology, each picture "fades" into the next (which as a matter of fact is a precisely correct statement), and thus the slight differences in position of moving objects are merged into continuous motion.

SETTING THE SHUTTER

(69) Setting a single shutter is an easily accomplished task, once it is understood that the function of its master blade is to cut all light off the screen while the film is in motion over the aperture.

Place the knob, or lever, by means of which the shutter is adjusted when the projector is in action (if any there be) at the center of its movement. Disengage the shutter hub from the shaft. Rotate the intermittent flywheel, by hand, in its direction of normal travel until the intermittent sprocket is exactly at the point of starting to move. If an "intermittent indicator" has not been supplied with the projector, wrap a piece of copper wire tightly around the sprocket hub, leaving one end stick out say 3 inches. By watching this wire-end the point of movement may be determined very accurately.

Having located this point, without disturbing the mechanism, rotate the shutter on its shaft in normal direction of movement until the leading edge of its master-blade is in position to cut off about two thirds of the light beam. Tighten the hub holding screws and the job is done, except possibly for some slight movement of the self adjuster knob or lever after projection is begun. Note: The manufacturer supplies a shutter-setting device with Simplex E-7, which latter has both a front and rear shutter involving special requirements for correct setting.

Setting shutters on a double-shutter mechanism involves special instructions applicable to the particular make and model mechanism in question. These can be found in the manufacturer's instruction book. (See Page 324.)

(70) Knowing that the shutter must have two blades, and that the flashes of light and darkness on the screen must be of almost equal duration (there may be some variation, but too much will result in flicker), it is evi-

dent that the narrower the shutter blades are the greater is the amount of light that will pass through to the screen. What then determines the necessary width of the master blade, and therefore of the cut-off blade?

You will recall that the master blade must be wide enough to "close the lens" while the film is in motion over the aperture, although, as indicated, a slight opening is permissible at the start and stop of the intermittent sprocket. It is evident, then, that the shorter the time the intermittent movement is in motion the shorter the time the lens must be covered. (71) Put another way, the faster the speed of the intermittent movement and, therefore, the intermittent sprocket action, the less time must be given to covering the lens and therefore more light will pass through to the screen.

The projectionist can do nothing to alter the intermittent speed. Most movements are now what are known as "three-to-one." One complete rotation of the cam carrying actuating pin D, Fig. 134, is one complete cycle of action. Divide that action into four equal parts: the intermittent movement star, and therefore the intermittent sprocket mounted on its shaft, is in action moving the film down through one of those parts, and standing still through three of them. (72) "Three to one" has been shown to be as fast a speed as the film sprocket hole edges and intermittent movement parts will stand. If it were faster, the movement would wear out too rapidly and the film sprocket hole edges tear up and break apart. For best results the film lies over the aperture three times as long as the film is in motion past the aperture.

OLD AND NEW IN SHUTTERS

(73) The old practice was to locate the rotating shutter on the screen side of the projection lens, having no effect whatever upon the heat which was concentrated continuously upon both the film and the projector mechanism cooling plate. Where a high amperage was used (or a reflector type lamp with no condenser to absorb and dissipate a portion of the heat) the film and the mechanism were both subjected to very high tempera-

tures, as a consequence of which the film buckled, and sometimes the projector mechanism frame was warped out of shape.

Later this type of shutter was replaced by the superior rear shutter now in very general use. It is located between the light source and the film, and since it cuts off a little more than 50 percent of the light (74), it cuts off an equal amount of heat from both the film and the mechanism. This shutter is available in two radically different types, each of which will be considered separately.

The Disc Type Rear Shutter

This type is, in effect, the old in-front-of-the-lens shutter somewhat enlarged in diameter and relocated just back of the projector aperture, (75) approximately five inches away. At this distance it must, with some types of beam converging element (lens or mirror), cut

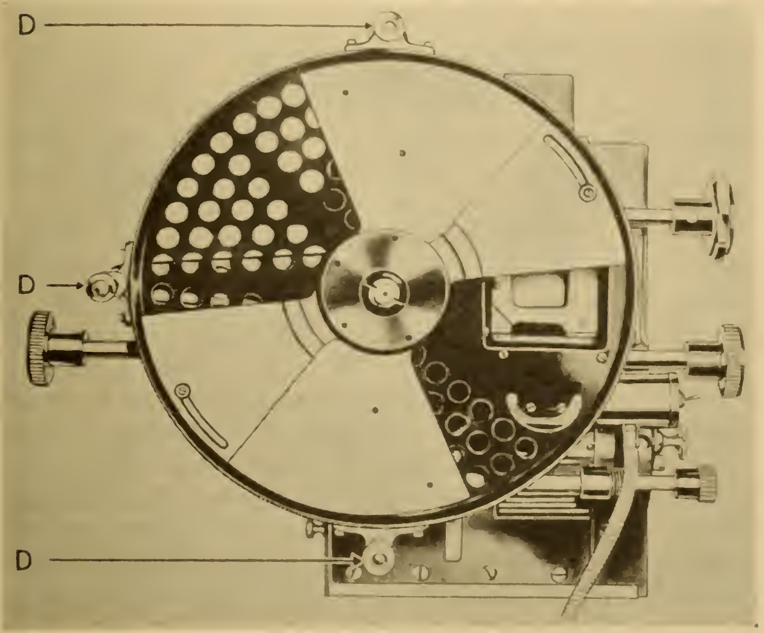

Fig. 138.—Simplex disc type rear shutter.

a light beam of considerable diameter, since the beam diameter in any direction is increased as the distance* from the aperture is increased. (76) In the Super Simplex, the center of the light beam is 3 15/16 inches from the center of the shutter shaft; hence the edges of the blades must travel at high speed at that point, cutting through the beam diameter very quickly.

In all circumstances the master blade of the shutter must be wide enough to shut all light from the screen while the film is in motion over the aperture, except for the slight leeway permissible at the start and stop as previously indicated. In other words, the width of the master blade depends to some extent upon the speed of the intermittent movement. Apparently the speed at which the edges of the master blade move decides, in a measure, the width of the master blade and the other blades. (77) The variation is small, but since the shutter goes into action 96 times each second (two blades, each with two edges), it is an item of importance.

(78) All modern shutters have two blades of equal width—hence either may be used as a master blade.

All rear shutters cause movement of the air around them. (79) In the Simplex disc type shutter, one side of each blade has a vane fixed at an angle to the line of rotation. This vane is approximately half an inch wide by about four inches long. When the blade is rotated at high speed the vane forces a strong current of air outward (toward the lamphouse), dispersing a considerable portion of the heat from the light source; the vane also draws air into and around the mechanism and helps to keep both the mechanism and the film at low temperature, without causing any great amount of dust to circulate from deposits at the aperture. All shutter blades are adjustable for width.

The Horizontal, Cylindrical Type Shutter

(80) This type of shutter is radically different in

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*The distance of the shutter from the aperture differs on different makes of projectors, though not very much. These quoted here are taken from the Super Simplex.

design and operation from the disc type. Essentially it is a hollow cylinder of metal, rotating in an enclosed housing.

(81) The Motiograph horizontal shutter is a light aluminum casting rotating on ball bearings and enclosed in a small metal housing. The shutter is positioned transversely (horizontally). In its cylindric surface are two openings through which the light beam passes; the rest of the cylinder serves exactly the same purpose as the blades of the disc shutter. Its cylindrical diameter is 3.25 inches. Its axis is 4 inches from the projector aperture. See Fig. 115, page 251.

(82) What is true of the speed and width of the disc type master blade edges does not apply to this shutter, and for two reasons: it is located closer to the projector aperture and consequently has a smaller beam diameter to cut; the shutter is positioned horizontally, or transversely of the beam, the light passes through its center or cylinder so that when one blade is cutting down through the beam the other is cutting upward, the two interacting at the beam center. Only half the time is required to cut off the light that would be necessary were only one blade in active operation. (83) Of the two blades each acts as a master and cut-off blade.

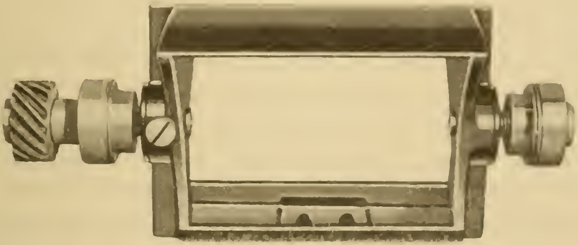

Fig. 139.—Motiograph Horizontal type rear shutter. This is the shutter used on the mechanism shown in Fig. 115.

The Motiograph horizontal rear shutter is shaped at each end of the cylinder to act like a fan or air propeller. From each end air currents are directed toward the center of the cylinder. Each of the two blades of the cylinder has a transverse vane, which, in combination with the propeller ends, sets up air currents and draws them in through the opening of the shutter housing at the cooling plate, and forces them out of the shutter housing toward the lamphouse. This draws air over the metal of the projector mechanism around the film gate, keeping it and the film at relatively low temperature and preventing deposits of dust.

The cylinder shutter, like the disc type, may be adjusted manually and may be partially adjusted while the projector is in motion.

Simplex Double Shutter

(84) The Simplex E-7 projector mechanism is equipped with both a rear and a front shutter blade, each of the ordinary disc type, both mounted on the same shutter shaft. Both rotate in the same direction. But they nevertheless produce the optical effect of cutting the light beam from opposite directions (as does the Motiograph cylindrical shutter) because (85) the projection lens is located between them and that lens reverses the beam so that its bottom rays on the lamphouse side are its top rays on the screen side. Therefore the action is exactly the same, in effect, as it would be were two blades, both located either in front of or at the rear of the projection lens, cutting the beam from opposite directions. Hence, the time required to cut light off the screen and restore it is reduced by one half as compared with the single shutter, and the screen receives proportionally increased total illumination. The two shutters are adjusted with relation to each other and to the beam by means of a special device supplied with each projector mechanism.

Correct Position for Front Shutters

(86) If an opaque sheet of material be held in front of a projection lens, an image of the converging condenser or mirror surface will be impressed thereon at a distance from the lens equal to the focal length of the lens. This point is known as the "point of aerial image." Its exact location may be ascertained by pro-

jecting white light to the screen and passing a sheet of opaque material, preferably metal, up or down through the light beam at different distances from the lens until a point is found where two shadows appear simultaneously at top and bottom of screen, meeting at its center. (87) It is important that the shutter be located at this point, both to obtain maximum screen illumination, and for (88) the dissolving effect produced. However (89) this latter effect will be the only gain unless the shutter blade width be reduced to the minimum width that will not produce travel ghost.

If the shutter shaft be too short to permit locating the shutter at the point of aerial image, then locate it as near there as possible and reduce blade width as above indicated.

(90) The projectionist may test for the width of his shutter blade in the following manner: remove the shutter from the shaft and the blade from its hub. Lay the blade on a piece of thin, stiff cardboard about 12 inches square and with a pencil trace the outline of the blade. Cut the cardboard pattern out and clamp it into the shutter hub, just as if it were the metal blade, and put the shutter back on the projector in its proper place. Don't bother to connect the outer edges of the paper blades; if the cardboard is strong it will run perfectly for several days without such connection.

Having set the cardboard blade properly, project a black and white title upon the screen and continue to trim off small but equal amounts from each edge of the master blade, after each trial projection, until a faint travel ghost begins to creep up and down upon the screen. Now the blade is just a bit too narrow on both sides. Remove it and trim the metal master blade to almost the same proportions, but a little wider to kill all traces of the travel ghost. Additional width, to be determined by the projectionist, must be provided or travel ghost will appear as soon as the mechanism gears and bearings begin to wear. (91) Trim the other blade to the same width as the master blade, always taking off an equal amount from each side. The shutter is now ready for efficient operation allowing maximum light on the screen.

TRIMMING THE REAR SHUTTER BLADES

Since the rear shutter is located a fixed, unchangeable distance from the projector aperture, (92) the projectionist is only concerned with the width of the blade and the air movement it creates. He need only ascertain whether or not the shutter is keeping too much light from the screen. He can do this easily if the shutter is an adjustable one, as most disc type shutter blades are: reduce the blade until travel ghost appears, and then increase the width slightly until it again disappears. (93) If the shutter has non-adjustable blades it is possible to make a test along the lines suggested for the front shutter, only an experimental blade of sheet metal, not of paper, must be employed for trimming. Because of the extremely hot light beam paper would be dangerous. This test can be made with the disc type shutter only.

(94) Since some theatres use a wide-diameter, close-up converging element, while others use a small diameter, far-away element, there is a decided difference in the beam depth to be cut by the shutter blades. (95) The difference may be observed by tracing on paper the outline of the two types and then measuring the depth of the effective beam at the point where the shutter is located. Shutter blades should be variously trimmed to cut the varying beam depths most effectively.

EFFECTIVE BEAM

(96) All light not falling upon the aperture opening is of no importance. The rear shutter master blade does not begin to cut light until its edge passes a straight line drawn from the top of the converging element to the top of the aperture opening—or from the bottom of the aperture opening to the bottom of the converging element provided the shutter runs in the opposite direction and starts cutting from below.

We have therefore coined the term "effective beam," this being the beam of light incident in whole upon the projector aperture. It may be defined as a cone of light bounded by straight lines drawn from the outer, free, diameter of the converging element (mirror or lens) to corresponding points upon the aperture opening.

Projector manufacturers hold this definition to be correct, but declare that the effective beam is bounded by straight lines reaching from the projector aperture opening to a rectangle on the face of the converging element, the same shape as the projector aperture, but so large that each of its corners would touch the converger's free diameter edge.

This statement is incorrect, for we discover that in some measure a round beam of light can be put through a rectangular opening. This may be proven by painting a converger (mirror or lens) with opaque water color and making a pin hole at its free diameter edge. Upon trial it will be found that a thin cone of light will go forward, some portion of which will always fall upon the aperture opening. It will be found by making other pin holes nearer the center of the converger that more of the spot light made by the cone will reach the aperture opening, until finally, near the center, it is likely the entire cone will enter the aperture opening and therefore become available to the projection lens. This pin-hole experiment should be very interesting to projectionists.

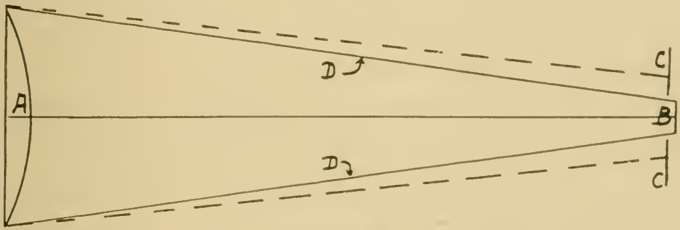

FIGURE 140.

The action of each cone of light may be investigated by blowing smoke into it. Tobacco smoke will serve, all film first having been put carefully away. A thin metal plate with drilled pin holes may be used, provided the experiment is made with a plano-face converging lens and the plate lies snugly against the lens.

(97) Projectionists may lay out the effective beam as per Fig. 140 in which line AB is on the optical axis and just long enough to reach from aperture B to plane of converger at A, broken lines representing the outline of the converger light beam as a whole. CC is the cooling plate.

All light outside of lines DD is wasted light and of no value when considering shutter action. The light between lines DD is the only light that is effective, hence it constitutes the "effective beam."

THE GEAR TRAIN

(98) The gear train not only drives the entire motion picture projector mechanism, but also, as previously stated, locks the intermittent movement cam with the rotating shutter so that they rotate in exact synchronism—the shutter making one complete revolution to each complete cycle of action of the intermittent sprocket. At 90 feet per minute projection speed the intermittent sprocket acts 24 times per second. Through the gear train the master blade of the shutter is made to cut off all light from the screen and to turn it on again at precisely the right instant of time.

(99) There is lost motion even in a new gear train —about 3/16 of an inch free movement of the intermittent flywheel while the shutter is held stationary. Projectionists should watch this carefully. New or repaired mechanisms that have a greater ratio of lost motion should be rejected.

(100) As parts of the mechanism wear, lost motion will increase. It should never be permitted to be more than 5/16 of an inch. If the ratio is higher it is evidence that the mechanism needs a general overhauling.

The gear train may not be altogether responsible for lost motion. Often it is due to worn bearings and other factors in the intermittent movement.

(101) To measure lost motion affix a prick-punch mark to some part of the mechanism frame as close as possible to the rim of the flywheel of the intermittent movement and a similar one near to the outer edge of the flywheel rim. By fixing one point of a calliper, or an ordinary carpenter's compass, in the mark on the frame with the other point at the mark on the flywheel rim, the distance the flywheel can be rotated may be accurately measured. Be very sure to hold the shutter perfectly still while testing the flywheel rotation.

The foregoing test was developed by projection manufacturers especially for the BLUEBOOK OF PROJECTION and has become the official, standard method of checking the gear train for lost motion.

GEAR LUBRICATION

Projectionists differ as to what constitutes the best form of gear lubrication. (102) Manufacturers recommend a fairly ample lubricant of a good grade of medium weight oil. A good quality lubricant keeps up a slow but constant washing of the gear surfaces and works out much more rapidly than heavy oil or grease, which collects dust and grit from the air. The ball bearings of the Century projector require no lubrication, and the gears of the Brenkert mechanism operate in a bath of oil. The projectionist should consult manufacturer's instructions for details of lubricating his own mechanisms. (See page 324.)

LUBRICATION OF BEARINGS

(103) One, or at most two drops of high grade oil are ample lubrication for any projector bearing. More may be thrown off, resulting in a messy mechanism and/or oily film. To reduce tendency to over-oil, use only a medium-size oil can with a small spout opening. Bearings other than those supplied by oil wells are above considered. The Simplex E-7 projector mechanism bearings are not oiled separately. Movement of a single lever lubricates all except those few points that require only very occasional lubrication.

SPROCKET IDLERS

(104) The function of holding the film close to the face of the various sprockets is performed by sprocket idlers, consisting either of one or two rollers per sprocket, or by a thin steel shoe.

Whether it is a shoe, a roller or rollers (some projectors have two rollers to each sprocket and some only one), the rule is (105) that the distance from the face of the roller or shoe to the face of the sprocket must be approximately one and one-half times the thickness of the film. (106) To arrive at this lay two thicknesses of film on the sprocket and adjust the roller bracket or the shoe firmly against the film with the adjustment screw in firm contact with the stop it rests upon.

(107) If the idler has been set too close to the sprocket face it will pinch the film. It will then start a tendency to side-weave, causing the sprocket teeth to climb out of the sprocket holes. If the shoe or roller is too far away the same condition may be brought about, though for a different reason, resulting in the loss of one of the loops. Proper adjustment of sprocket idlers is important.

(108) It is also important that each end of the sprocket idler be exactly the same distance from the sprocket face, since any variation will cause the film to pull sidewise away from and off the sprocket teeth. (109) If the idler is a roller it must be kept well lubricated with a thin oil, else it will stick and quickly wear flat on one side. In that case it must be replaced immediately. Do not use heavy oil. The much advertised household oils are excellent for this purpose; or the oil you use for the projector, mixed half and half with kerosene, will do very well. All idler rollers, including those of the fire trap, should be inspected each day before the first run to make sure they are rotating freely. Sprocket idler rollers should be given one drop of oil each day, wiping all surplus oil carefully away.

UPPER MAGAZINE TENSION

Every first class projector is equipped with some sort of device to supply tension to the reel in the upper magazine (110) to hold it in retard. This brakes the momentum of the reel, which otherwise would continue to run rapidly after the projector is stopped. Should that occur, when the projector is again started and the slack is taken up, the reel will start with a hard jerk, which is likely to pull the film apart. The necessary tension may be determined by experiment outside of show hours, starting and stopping the projector several times, meanwhile adjusting the tension until the braking effect is sufficient.

Take-Up Tension

The reel in the lower magazine must take up (rewind) 90 feet of film per minute. At the beginning, when the film roll is small, the reel rotates at high speed, gradually slowing down as the diameter of the roll increases. (111) To provide for this continuous change in speed, slippage is provided for between the driving pulley and take-up reel spindle. In one simple form this slippage consists of two metal discs, several inches in diameter, between which is a plate of fibre friction material. These two discs are held together by spring pressure sufficient to provide friction to drive the take-up spindle, at the same time allowing slippage to compensate for the continuous change in speed. (112) The spring pressure should be as low as is necessary to keep a slow moving film-laden reel in rotation until the end of the run. Adjust the tension so that when the reel is full its rotation may be stopped by a slight touch of the finger at the rim of the reel. (113) Too much tension is bad. It is hard on the film sprocket holes; it wears the lower or "hold back" sprocket teeth unnecessarily. There must be just enough to drive the reel without danger of it stopping.

Magazine Rollers and Fire Trap

The rollers are presumed to make it impossible for fire to get through the fire trap. They are spaced exactly right by the manufacturer, the maximum distance being fixed by Underwriter's rules. (114) Where old films are usually used the fire traps should be examined once each day. When using new films, upon which the emulsion is soft, the rollers should be examined after the projection of each reel to make certain no deposit of emulsion has accumulated. (115) The fire trap rollers are made of material that requires no lubrication, but if lubrication seems necessary, use only a light oil sparingly.

Path of Film Through Projector Mechanism

(116) Projectionists should make a thorough daily inspection of the entire path of the film (commonly called the "film track") through the projector mechanism between and including the upper and lower magazine fire traps. (117) If first-run films are used inspections must be made after each run to make sure no deposit of the soft emulsion has accumulated at any point. A vast amount of damage, in the form of scratches in the emulsion, is inflicted upon film every day by these deposits of emulsion on metal.

In inspecting the film track, run your fingertips over each inch of flat space which the emulsion side of the film contacts in its course from upper to lower magazine; also examine the fire traps and sprocket idler rollers for the same troublesome emulsion deposits.

(118) The aperture plate tracks or surfaces of the tension shoes (whichever the emulsion side of the film contacts) should also be carefully inspected before each reel is threaded in, unless only old, well-seasoned films are used.

(119) The film must pass through the projector and sound mechanism in a perfectly straight line. (120) It is guided past the apertures of both projector mechanism and sound head by lateral guides, which should never be disturbed except to be replaced. (121) Assuming these guides to be rightly placed, the correctness of the path of the film elsewhere may be judged by examining the loops (see Fig. 136), which should set perfectly "square." If either or both of the loops are at all distorted (crooked) it is- -unless caused by the presence of

a poor film splice in the loop—evidence that something requires immediate attention.

If it becomes necessary to remove and replace a lateral guide follow the manufacturer's instruction book, or if this is unavailable secure detailed instructions by addressing the projector manufacturer. Correct placement of the lateral guides is necessary to good projection.

The Automatic Fire Shutter

All projectors are equipped with an automatic fire shutter (122) consisting of a mechanically controlled sheet of metal that drops down, automatically, between the cooling plate and aperture, cutting off all light from the film and the screen the instant projection speed is reduced below the safe limit, which is the moment the film is in danger of ignition because of the slowness of its passage through the intense heat of the spot.

(123) The mechanical operation of the fire shutter varies widely in different makes of projector, but in none of them does it require much attention beyond lubrication. (124) The fire shutter should not rise until projection speed has fallen to at least sixty (60) feet of film per minute. It should drop automatically when projection speed falls below sixty feet of film per minute. (125) Projectionists should check the rising and falling speeds of the shutter at least twice a week to make sure the device is operating properly. Improper action of the fire shutter is a decidedly dangerous condition, especially in one-man rooms.

Size of Loops

(126) Between the upper and lower loops in the projector mechanism the film moves intermittently exactly three-quarters of an inch each time. Both loops must therefore contain that amount of slack film, and a little more. (127) To arrive at the required loop size, thread in a film and operate the mechanism slowly by means of the flywheel; watch the loop action and gradually diminish the loop length until it has just the amount of slack

necessary for smooth operation. Some projectionists prefer to make the loops as large as possible without forcing the film to rub on the upper or lower fire shields.

(128) In closing the subject of the projector mechanism we must stress again the importance of keeping it scrupulously clean. Lubricants should be selected carefully unless the one recommended by the projector manufacturer is used. Do not expect any projector mechanism to give good results unless it is kept in a state of repair and in perfect adjustment, and remember that "repair and adjustment" includes frequent, thorough inspection of the various parts.

(129) In addition to the foregoing general instructions, the projectionist needs very specific information about the particular make and model of the mechanisms entrusted to his care. These mechanisms are expensive. A fault in their operation can cause fire. The projectionist needs to know all he can about them, and different makes and models vary so greatly that detailed information about all of them cannot be included in the space available in this Bluebook. That data, for all projectors now on the market, would come close to filling another Bluebook the size of this one. The place to go for it is the instruction book of the manufacturer of the mechanism in question.

(130) Such instruction books are made available by manufacturers without charge or at nominal charge. They confine their information to concrete data. For example: (a) at what points of the mechanism should lubrication be applied; (b) how often and how much lubricant should be applied at each point; (c) what type or types lubricant should be used. Manufacturer's instruction books also often explain just how to go about removing and replacing a given gear or other item, down to such details as which screw to take out first. Also, they commonly contain diagrams in which every gear, shaft, sprocket, nut, bolt, screw or other part is identified by number. The best way to order a replacement is to identify the part needed by the number given in the manufacturer's book or pamphlet.

Travel Ghost and Rain

(131) As has been explained, the screen image would be hopelessly blurred if there were no shutter to cut off the light while one photograph is removed from the aperture and another replaced therein. The whiter portions of the image, in particular, would be mere vertical streaks on the screen. And if the shutter blade width is reduced too much, permitting more than a minimum of light to reach the screen while the film in the aperture is in motion, a partially streaky effect will be produced. This is called travel ghost. Travel ghost is most easily seen in titles, where white letters against a black background show a grayish "ghost" of part of each letter above or below the letter proper. A similar effect, of course, occurs in each picture, blurring it. Not only incorrect trimming of the shutter blades, but any misadjustment or faulty action of the shutter or the gears that drive it, may produce travel ghost if the misadjustment or faulty action has the effect of admitting more than a minimum of light to the screen during the time film is in motion in the aperture. To eliminate this blurring effect the mechanical cause of the incorrect shutter action must be run down and corrected.

(132) Rain is a term applied to thin streaks, like driving rain, appearing in the screen image. These are always the fault of some projectionist, for they represent scratches in the film, which scratches in turn were caused by dirt in someone's projector mechanism. This dirt may be no more than particles of emulsion, or of film coating material, which accumulated in the projector because it was not scrupulously cleaned after every reel. If the projectionist is careless about this matter, a film that arrives in the projection room in the morning in perfect condition may be badly rain-streaked before the end of the last evening show. And the damage is beyond repair; nothing can be done for a rain-streaked print except to scrap it. The duty of the projectionist in this connection is too obvious to need comment.

THE PROJECTION ROOM

Practical Questions

(For answer to each question see statement of corresponding number in Chapter XIII)

1. Why is the projection room the vital part of the theatre?
2. Upon what does excellence of projection depend?

GOOD WORKING QUARTERS IMPORTANT, PAGE 331

3. Can projectionists do their best work in badly planned projection rooms?

LOCATION, PAGE 331

4. What is an important point in the location of the projection room?
5. What should be the limits of projection distance?
6. Name the objections to too-short or too-long projection distance?
7. Is it sometimes commercially advisable to sacrifice seating space to avoid a poor projection room location?

CONSTRUCTION DETAILS, PAGE 332

8. Are insurance rates higher if the projection room is faultily planned and constructed?
9. Should exhibitors examine into insurance rates and the effect projection room planning has upon them?
10. Is the old style projection room effective in either fire or sound proofing?
11. Describe one form of projection room wall construction that is now much used.
12. Name another excellent building material for projection room walls.
13. What is essential in connection with hollow tile walls?

14. What finish on both sides should hollow tile walls have?
15. When should conduits be put in place?

PROJECTION ROOM CEILING, PAGE 333

16. Should exhibitors give careful consideration to ceiling construction?
17. What is a satisfactory substitute for a ceiling?

PROJECTION ROOM FLOOR, PAGE 334

18. Describe method of building a concrete floor.
19. How thick should the concrete underlay be?
20. Should a cement floor that is to be used without covering or treatment be of high grade cement?
21. Is it good practice to use a raw, uncovered, untreated cement floor?
22. What is the best cement floor covering?
23. What should be done if battleship linoleum or its equivalent is not used?

DIMENSIONS OF ROOM, PAGE 334

24. How high should the ceiling be?
25. What should be the length of the projection room?
26. What should be the depth from front to rear wall?

SPACING THE PROJECTORS, PAGE 335

27. State a good rule to follow in spacing projectors.

LENS AND OBSERVATION PORTS, PAGE 335

28. How large a wall opening should be left for lens ports?
29. May openings (ports), other than those used for observation be reduced in area?
30. What is the governing factor in the size of observation ports?

31. Do observation ports less than twelve (12) inches square offer any elements of safety?
32. What should the size of observation ports be?
33. What should be the distance from the floor to bottom of observation ports?
34. What should be the color of the wall immediately surrounding observation ports?
35. What should be the size of the effect and stereopticon lens ports?
36. What governs the size of spot light ports?
37. Should spot ports be covered with glass?
38. Should ports in thick walls be flared outward?

CONDUITS, PAGE 338

39. Who should be consulted before installing conduits?
40. Should conduit runs and outlets be indicated on the building plans?

LIGHTING THE PROJECTION ROOM, PAGE 339

41. Why is projection room lighting important?
42. What will reduce the ability of projectionist to see the screen image clearly?
43. How may the effect of improper lighting be tested?
44. How is the projection room properly illuminated?

TROUBLE LAMPS, PAGE 340

45. Should every projection room be equipped with at least one trouble lamp?
46. What kind of a trouble lamp is best and how much cord should it have?
47. How is its reel controlled?

RHEOSTAT ROOM, PAGE 341

48. Should rheostats be located in the projection room?
49. Is a separate rheostat room conducive to safety, health and comfort?

MOTOR GENERATOR AND BATTERY ROOMS, PAGE 341

50. Where should the motor generator sets be located?
51. Should the motor generator room be sound proofed?
52. May batteries be located in motor generator rooms?
53. Where should storage batteries be placed?
54. Are unprotected wood floors proper in a battery room?
55. Are storage batteries adversely affected by extremes in temperature?

VENTILATION, PAGE 341

56. What is the real value of projection room ventilation?
57. From where must air for ventilation be drawn in?
58. Where is it best to place fresh air inlets and the outlet?
59. With what should inlet openings be covered?
60. What about the size of inlet openings? How should the amount of air be controlled?
61. Is it safest and best to have an outlet of ample area?
62. What is likely to happen if a film fire occurs and the outlet is not of sufficient dimensions?
63. Is forced ventilation desirable?
64. Describe a method of operating forced draft ventilation consistent with health and comfort?
65. Describe a separate system for removal of smoke and gas in the event of a fire.
66. Can a fan be installed to do double duty for ordinary ventilation and for fire emergencies?
67. How large must a fan be to remove smoke and gas?
68. What is the plan for smoke removal illustrated in Fig. 143?
69. Must the outlet duct for such a system as shown in Fig. 143 be insulated from inflammable material?
70. Why is it bad practice to install the motor in outlet duct?
71. What is the chief point in the plan shown in Fig. 143?

PAINTING THE PROJECTION ROOM, PAGE 345

72. What kind of paint should be used for projection rooms?
73. What should the colors be?
74. What should be the color around observation ports?
75. In what color should auxiliary rooms be painted?

PORT FIRE SHUTTERS, PAGE 346

76. Of what material should port fire shutters be made?
77. What danger sign first excites an audience?
78. What is the real purpose of port fire shutters?
79. How are shutter grooves made?
80. What should be placed in the bottom groove and why?
81. Can ready-made metal port casings be obtained?
82. What is essential to quick action of the port fire shutters?
83. Why are metallic fuses unreliable for quick action?
84. Must all sound be confined to the projection room?

GLASS IN PORTS, PAGE 347

85. Is optical glass for port coverings practical?
86. Why is it necessary to set observation port glass covers at an angle?
87. How should port cover glass be mounted?

LENS PORTS, PAGE 348

88. Should lens ports be covered with glass?
89. Why should the lens ports be kept open if possible?

THE PROJECTION ROOM ENTRANCE, PAGE 349

90. What should the door dimensions be?
91. Why should there be two doors, with a space between?
92. What kind of door should be used?
93. What, on the whole, constitutes a good projection room?

PROJECTION ROOMS IN VERY SMALL THEATRES, PAGE 351

94. What standards have been proposed for projection rooms in extremely small theatres?

CHAPTER XIII.

THE PROJECTION ROOM

(1) The projection room is the very heart of the theatre. It is the working place of men who are called upon to recreate the performance of great artists, both in pictures and in sound. (2) Whether the recreation is good or bad depends to some degree upon the appointments and general conveniences of the projection room itself. (3) Men engaged at tasks that require intelligence and skill cannot be expected to work efficiently in quarters that are badly ventilated, cramped or devoid of simple necessities.

LOCATION

(4) In locating the projection room avoid projection angles, if possible, to eliminate distortion on the screen. The maximum angle approved by the Society of Motion Picture Engineers is 14 degrees. Laterally (sidewise) the room should be located so that where there are two projectors each projector will be located equidistant from a line at right angles with the surface of the screen at its center. Where there are three projectors the lens of the center projector should be on this line.

(5) The projection room should not be too close to the screen or it will require the use of a projection lens of less than 4 inches E.F.; nor should it be too distant, or it will require the use of a lens exceeding 7 inches E.F.

(6) The use of a too-short focal length projection lens makes it impossible to secure sharp definition (focus) all over the screen, a condition that induces eyestrain. The use of a projection lens of more than seven inches E.F. may mean that not all of the light beam will enter the lens, resulting in loss of light and uneven

illumination of the screen. This condition can be sometimes overcome by using an expensive wide-diameter lens.

SACRIFICE SEATS

(7) In some cases side and front seats may have to be sacrificed to avoid a very steep projection angle. The use of a too-long or too-short E.F. projection lens may also be avoided by the elimination of a few objectionable seats. The better screen image obtained by the correct location of the projection room is one of the important factors that keeps patrons continuously satisfied. Nothing is so ruinous to the success of a theatre as distorted or badly illuminated projection.

CONSTRUCTION DETAILS

(8) Too little attention given to the proper fireproofing of projection room walls, doors or ports during construction often means unnecessarily high insurance rates. (9) Careful planning to meet all local and national fire regulations means a great saving in insurance rates.

SOUND AND FIREPROOFING

These two items are so closely connected that they may be considered under one heading. (10) The old projection room wall of steel, asbestos board, metal lath and plaster gave a measure of fireproofing, but failed altogether to meet the requirements of soundproofing. (11) One modern practice is to construct walls of double-channel studs, fixing a substantial metal lath on each side and coating them with an approved cement plaster not less than three-quarters of an inch thick. This form of construction (provided a high grade portland cement is used) forms two solid walls, between which is dead air space and plenty of room for conduit. Metal brackets to receive any desired shelving or benches may be attached to the studs before the plaster is applied. When this type of wall is employed, the outer plaster surface is heavily coated with a good plaster-finished acoustical material. Such walls are light in weight and do not store heat or cold to any considerable degree.

(12) Hollow tile is light in weight, has excellent fireproofing qualities and fine soundproofing characteristics and does not store heat or cold appreciably. Hollow tile not less than three inches thick forms the best type of projection room wall, provided the front wall has a good underlying foundation and the tile is laid in good cement mortar tempered with lime—to make the mortar work well. (13) A good foundation for the front wall is necessary because the cutting of the ports weakens its strength considerably.

(14) All walls abutting upon the auditorium should be plastered on the inside with cement mortar to a thickness of at least three-fourths of an inch. A three-quarter-inch-thick coating of acoustical plaster (or concrete) should cover the auditorium side. Walls treated thus will be strong enough, despite the port openings. (15) Conduit should be built into the wall.

The Ceiling

(16) Many theatres are paying high insurance rates because of improperly constructed projection room ceilings. (17) All requirements are met if the room walls join a concrete floor above. Otherwise either of the following two suggestions are practical: Use a 4-inch hollow tile supported by suitable T beams, laying the tile in cement mortar in the same manner as the tile walls. First apply a layer of cement mortar three-quarters of an inch thick and over that—for surface covering—lay a coat of acoustical plaster of the same thickness. Or use iron I beams, each not less than three inches deep, with metal lath above and below, laid in plaster. Two-inch beams are used frequently but these are too light for a deep room.

It is wise to consult local authorities before finally deciding upon any form of wall or ceiling construction. Frequently they insist on certain types of material and construction.

THE FLOOR

(18) The best floor is a top dressing of high grade cement and sharp sand (insist upon the high grade cement and "sharp" sand) laid down not less than one inch thick, supported by a substantial thickness of rich concrete of cement, sand and medium-size crushed stone well tamped into place, with all the various projector and other necessary anchor bolts, conduit, etc., embedded therein. (19) The concrete underlay should be of sufficient thickness to be impervious to vibration set up by the machinery. Be guided by the architect on this point, though a six-inch thickness should be quite sufficient.

(20) Unless the floor is to be painted or covered with linoleum or other material, it is imperative that only high grade cement be used for top dressing. Poor quality cement will be scuffed up rapidly into dust, which will settle on the film, causing minute scratches, get into the machinery bearings and cause them to wear very fast, get into the sound equipment and cause noisy sound. The best cement will do this to some extent, but a poor quality deteriorates quite rapidly.

(21) Under no circumstances is it good practice to use a floor of raw cement in a projection room. (22) The best covering is "battleship linoleum," dark green or brown in color, cemented to the floor. (23) If linoleum is too expensive, cover the floor with two coats of paint. There are acid treatments that do fairly well in preventing dust formation, but paint is more reliable, and linoleum the best.

DIMENSIONS OF ROOM

(24) Under no condition should the ceiling be less than eight feet from the floor in cool climates. It should be twelve feet in warm climates. The higher the ceiling the better.

(25) The length of the room is dependent upon the number of projectors and other equipment it has—such as spots, effect projectors, stereopticons, etc. Starting

with 8′ width for a one-projector installation, six feet are necessary for each additional projector, spot lamp, effect projector or dissolver and a reasonable allowance should be made for additional equipment in the future.

(26) Depth, from front to back wall, should not be less than ten feet where no sound or other apparatus is to be installed along the rear wall. This provides approximately three feet of clear space back of the projectors, assuming them to be set as close as practicable to the front wall. Where equipment is to be installed against the back wall, the depth of the equipment plus any space required at its rear must be added to the regulation depth of ten feet.

Spacing the Projectors

(27) Since projection distance dictates the angle of the optical axis of each projector to the screen surface, the following is a safe rule to follow: if the projection distance is less than 75 feet the distance of the lens center of one projector to the lens center of the second should not exceed four feet. If the projection distance exceeds 75 feet but does not exceed 125 feet, the spacing should be increased to four and one-half feet. If the projection distance exceeds 125 feet, the spacing then should be increased to five feet, all distances measured from lens center to lens center.

Lens and Observation Ports

(28) The projector lens port wall openings should be at least 12 inches high by 10 inches wide. The area of these wall openings should be reduced later to just a little more than is necessary to accommodate the light beam. This reduction should be made after the projectors are finally anchored in place and the light properly centered upon the screen.

In Fig. 141 we see a lens port approximately reduced to the area of the light beam making the use of glass over lens ports unnecessary.

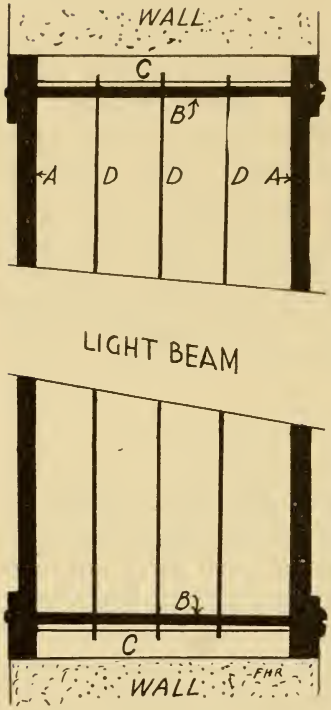

FIGURE 141 *

Parts AA are two pieces of fairly stiff, fireproof, sound absorbing material from ⅜ to ½ inch thick, cut to fit snugly but not too tightly into the wall opening at either side of the wall. The surfaces of these plates, on the projection room side at least, should be inset just enough so that iron holding straps will be flush with the face of the wall, thus avoiding interference with the port fire shutter. The holding straps are merely to reinforce parts AA and keep them from warping. A second set of straps may be run up and down if it is thought necessary. Parts AA are secured to the straps by means of rivets.

CC are two pieces of the same material as AA, but no less than one-half inch in thickness. Parts AA are held firmly against the edges of CC by bolts BB, which should be threaded into the inner strap to avoid possible interference of nuts, if used, with fire shutters.

Parts DDD may be set into slots in parts CC which may be saw kerfs, or slots may be made by affixing strips of the material from which parts DDD are made to plates CC, separated to form the slots.

Fig. 141 shows the construction plainly. First, build the entire device at the bench so that it will fit into the wall opening snugly and may be easily pulled out again. When it is finished, install it in position in the wall open-

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*This construction is covered by patent.

ing and, with the projector anchored permanently in its place and the light properly centered on the screen (use the magnascope lens if one is provided), project the light beam upon part A nearest the lens. With a pencil trace the beam outline on the part, remove the whole device to the bench, take out Part A, cut a hole therein just a little larger than the actual beam, reassemble, replace in the wall opening and do the same thing with every one of the obstructing sheets of material.

When you have finished you will have a port just a trifle bigger than the light beam, with a sound baffle that should make a glass cover, except possibly in very thin walls, unnecessary. Cement around the edges, both inside and out, with half good, clean sand and half cement or plaster of paris.

Three baffle plates should be sufficient, but in case of very thick walls four might be used to more advantage.

(29) Lens ports and openings other than observation ports should be no larger than is actually necessary but (30) observation ports should be large enough to afford a clear view of the screen from any normal working position beside the projector.

(31) Authorities who compel reduction of observation ports to less than twelve inches square gain nothing in added safety, but do reduce the efficiency of the projection crew. They forget that ports are now invariably glass covered and a fire shutter will drop and cover a twelve-inch opening just as quickly as it will cover one of smaller dimensions.

(32) Observation ports should be fourteen inches high by twelve inches wide, covered with glass. (33) The bottom of these observation ports should be so located that a line drawn from a point opposite the light source, and 60 inches away from the floor, to the lower edge of the screen image will just miss the port bottom. This makes certain a full view of the screen image from working position regardless of the projection angle. (34) The wall surrounding each port should be painted in a non-gloss black color for a foot and a half in all directions.

OTHER PORTS

(35) Wall openings for effect and dissolving stereopticons should be stepped down until they are no larger than is necessary. It is best to start with ports of ample dimensions. After the projectors are permanently located and anchored down, project the light beam upon the openings, first shutting them off with a fireproof, sound absorbing material. The dimensions of the beams can then be marked, the piece removed and an opening cut in it the size of the light beam. The final openings may then be covered with optical glass if desired.

(36) The width and height of ports for spotlights will depend entirely upon how close the lens is to the wall and through how wide an angle it is necessary to swing the light beam. (37) Some theatres do not close spot ports with glass, opening the fire shutter only when the spot is in actual use, and at this time no conversation or other unnecessary noise should be permitted. In some cases local authorities demand that spot ports be covered with glass.

PORTS FLARED

(38) If the front wall is more than eight inches thick it is advisable to flare (slope) the bottom of all ports downward, at least to the angle of the axis of projection, provided it exceeds five degrees. If the wall is twelve or more inches thick, both bottom and sides of ports should be flared outward. This applies to all port openings.

CONDUITS

(39) Before installing sound equipment conduit the equipment manufacturer should be consulted and his advice followed. Unless this is done, very serious inconveniences may be encountered later on. (40) Exact location of all conduit runs and outlets should be indicated on the projection room plans, so that they may be embedded in the walls and floors during construction.

Lighting the Room

(41) Projection room illumination should be most carefully designed. Theatre projectionists are engaged in producing certain effects upon an illuminated screen located from 50 to 150 (or more) feet away. They must have the best possible view of the screen, yet this view can be had only through a wall opening of necessarily restricted size.

(42) It is easily understood that if the wall immediately surrounding the port opening is illuminated, or if any light in the projection room shines in the eyes of the projectionist, his view of the screen is hampered. And it is a fact that even today both these bad characteristics exist in projection rooms that are otherwise quite intelligently arranged.

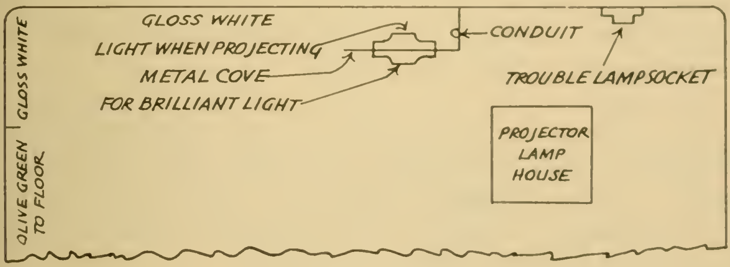

Figure 142

(43) Enter any well illuminated projection room, take your place in working position beside a projector, watch the screen—then suddenly have the room illumination turned off. You will be amazed at the increased clearness with which the picture details on the screen can be discerned.

(44) Following is what we regard as a good plan for projection room illumination. Fig. 142 shows an end view of a sheet metal cove attached to the ceiling, its length extending to within six feet or less of each wall.

The cove should be located over the rear end of the projector lamphouses. Its interior, the ceiling from it to the rear wall and a sizable section of the rear wall down from the ceiling, should all be painted a gloss white color. All other wall surfaces should be a dark olive green or dark brown color, except a strip 18 inches wide, in flat black color, around the observation ports and around the metal surfaces of the port fire shutters.

Enough incandescent lamps should be installed in the cove to provide a reasonable amount of illumination during projection. Fig. 142 will show that all of those lamps are completely concealed from view of the projectionist except when he is near the rear wall. We also see that all light comes in diffused form from the rear of the ceiling and from the top of the rear wall, falling upon the back of the projectionist and not upon his eyes when he is in working position beside the projector. The rear of the room can be well illuminated. The only possible objection to this plan is that the equipment will throw shadows on the front wall, but this is of little importance. Projectionists who have used this lighting system prefer it above all others.

The lights in the cove provide sufficient illumination in the projection room at all times for all requirements. Provision should be made in the cove for a secondary circuit to give brilliant illumination when projection is not in progress. The use of this second circuit should be severely prohibited during projection.

Trouble Lamps

When trouble occurs at one of the projectors ample illumination should be concentrated there. (45) For this purpose every projection room should have at least one reel-light; in large rooms two or more reel-lights should hang at convenient points. (46) A reel-light is a lamp at the end of a long cord which is wound on a reel mounted on the ceiling. The lamps can be carried to any part of the room and to every piece of equipment. (47) The reel is spring-controlled, so that the cord will automatically rewind itself and remain out of the way until the lamp is needed. Reel-lights may be bought from any first class supply dealer.

RHEOSTAT ROOM

(48) If rheostats that are not units of the motor generator equipment are employed to control projection current, they should be located in a separate, thoroughly ventilated room adjacent to the main room. (49) This is necessary not only for the comfort and health of the projectionists, but also as a matter of safety. Hot rheostat grids or coils, and inflammable film, are dangerous combinations in the same room.

MOTOR GENERATOR ROOM

(50) Motor generator sets should be located in an airy room adjoining the main projection room. There should be sufficient free space around them to enable all necessary work to be carried forward with reasonable convenience. (51) The generator room should be sound-proofed. (52) Never locate storage batteries in the same room with motor generator sets or other electrical equipment.

BATTERY ROOM

(53) Storage batteries should be located in a separate room connecting with the projection room. When charging, batteries give off spray that is injurious if breathed in considerable quantities, and likewise does serious damage to the insulation of electrical equipment nearby. This spray must be exhausted to the outer air as fast as it forms.

(54) Wood floors in battery rooms should be covered with linoleum or painted with an acid-proof paint. Battery acid and spray will rot an unprotected wood floor quickly and may cause accidents.

(55) Storage batteries may be adversely affected by extreme temperatures, either hot or cold. They should never be in the same room with rheostats, nor exposed to low temperatures through improperly placed ventilators.

PROJECTION ROOM VENTILATION

(56) Proper projection room ventilation is important for a number of reasons, each one of which deserves

the very serious consideration of architect and theatre owner. It is important to the health and comfort of the men who work for long hours in a confined space under very difficult conditions at best. It is just as important as a safeguard when a fire starts in the projection room. And, unless removed by lamphouse ventilation, the minutely fine particles of carbon powder given off by the carbon arcs will enter the switches, volume controls and tube sockets of the sound system and lodge on the film, producing minute scratches. Adequate ventilation will avoid all these troubles.

(57) Plenty of fresh air should be supplied—not taken from the auditorium, but from outdoors. (58) If the room is longer than it is broad, the air should come in near the floor level at each end and find its outlet at the ceiling line at its center, thus sweeping through the entire room. If the room is somewhat square, the air inlet may be at the floor line either at each side or at the rear wall, and the outlet in the center of the ceiling. (59) The inlet opening in all cases should be covered with galvanized wire screen of about one-half inch mesh

(60) The inlet openings must have sufficient area to admit a plentiful supply of air. Shutters should be adjustable, so that the amount of incoming air can be regulated at will.

(61) The outlet must have ample area, not only for ordinary ventilation but also, in the event of a film fire, to enable the quick escape of all gases and smoke as fast as they form. (62) Otherwise they will seep into the auditorium, perhaps causing fatal consequences. Gases pass quickly through crevices around the glass covers of port openings. When they can't escape they blind and overpower the projectionist, driving him from the projection room. With the fire out of control anything may happen.

If ventilation is by natural draft, both inlet and outlet must be much larger than where forced draft is employed.

(63) Ventilation, save in exceptional cases, should be by forced draft. The heat generated within the

lamphouse is unbearable. Natural air movement may serve in time of cold weather but in the hot summertime it fails utterly to provide the necessary relief.

But consider the importance of forced draft if a fire in the projection room occurs. By turning on the full power of the ventilating fans as soon as a fire breaks out, the air will be sucked forcibly and rapidly away from the auditorium side and—if the port shutters are closed at once—not even a wisp of smoke or gas will be allowed to pass through the crevices. The audience will not be aware of a fire.

(64) Authorities recommend that projection room ventilation, for reasons of health, should be effected through the theatre's forced draft system where there is one, and that a separate fan and outlet be provided for emergency use only in the event of a fire. If there is no forced draft system, then a fan of proper capacity should be installed in the lower end of the outlet air duct and all inlet air ducts shuttered so that the flow of air may be controlled to meet varying conditions. The Society of Motion Picture Engineers normal venting of each lamp at the rate of 15 cubic feet of air per minute, with an emergency blower capacity of 400 cubic feet of air per minute. These figures apply to lamp ventilation only. For the projection room as a whole a system with a 200 cubic feet per minute normal capacity, and not less than 1,000 cubic feet per minute emergency capacity, is recommended.

(65) In addition to this it is advisable to install an exhaust fan removed from places where fire is likely to originate. It may be installed in a fireproof cabinet in the main projection room, connecting with an outside air duct. Normally this fan is controlled by a switch held in closed position by a spring, but during the hours of operation it is held open against the action of the spring by means of a strong cord, wire or chain attached to the port fire shutter master control. When, in an emergency, the shutter control is released, it will close the switch, thus instantly putting the exhaust fan into action to the limit of its power. The plan is roughly

outlined in Fig. 143. If preferred the fan may be located entirely outside the projection room.

(66) The method may be utilized in either of two ways. The fan ordinarily may be used to ventilate the projection room by installing a speed control device so that it will operate at the required speed. The speed control must be so connected to the port shutter master control that when it is released it will instantly energize the fan to its full power.

The other way, when there is no forced draft system, is to install a separate, smaller fan in the outlet duct for ventilation purposes only, using the large fan for emergencies like fire. In this case it will incur no operating expense nor will it suffer deterioration from wear. It has a distinct value as insurance against the possibility of panic in the event of fire.

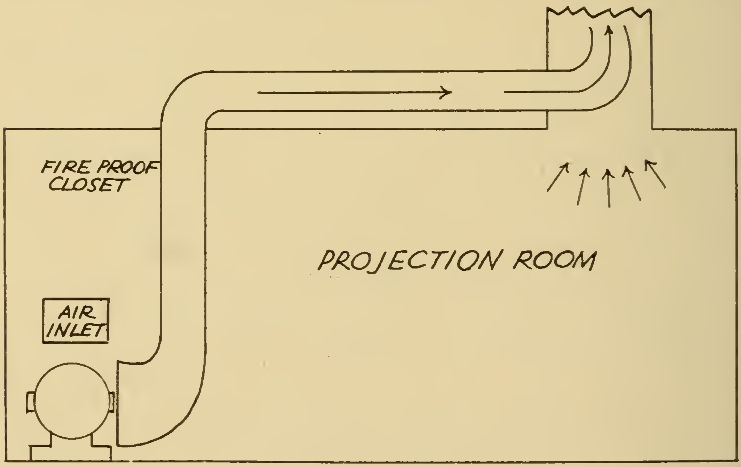

Figure 143

(67) To be effective the fan must be large enough to create a slight vacuum in the room; therefore it must be arranged to permit the inlet opening shutters to close automatically as soon as the port shutter master control is released. An auxiliary switch should be provided to open the fan circuit when the port shutter master control is released normally, as at closing time.

(68) In Fig. 143 it will be observed that the arrangement provides for an air injector, or ejector if you like that term better. It is very powerful in creating air movement.

(69) The air outlet should be of fireproof material, well insulated from all combustible matter nearby. There must be no sharp bends or elbows in the exhaust duct. The fan can be installed in the lower end of the duct itself provided the duct has sufficient diameter, and the fan can be geared to a well-protected motor. (70) Do not install the motor in the duct because it will be in the path of hot air and possibly flame and would be put out of commission immediately in case of an open film fire. The accompanying drawing is designed only to convey the general idea. Details of installation will vary widely for each theatre.

(71) What is wanted is plenty of fan power that will cut into maximum power the moment a fire starts, with the driving motor well protected from heat.

Painting the Projection Room

(72) When the cove trough method of lighting is employed use non-gloss paint because it has least light reflection powers. A gloss white paint is best for the portion of the ceiling at the rear of the cove trough, and on the upper portion of the rear wall. The lower portion of the rear wall, the entire side walls and the front wall should be in either dark olive or dark brown color, well stippled to reduce reflection. The ceiling in front of the cove trough may be any color, but a light buff is suggested. It is, perhaps, not a pretty shade, but it serves projection requirements most efficiently.

(73) Where the room is lighted in the usual manner, the rear and side walls, including all doors, should be painted a dark color, preferably an olive green or dark brown, seven feet high in an 8-foot ceiling room or eight feet in a higher room. The front wall should be darker than others — the darker the better. Dark olive green or its equivalent in brown will serve well. (74) All front wall metal work and an eighteen-inch area surrounding

observation ports should have two coats of flat (non-gloss) black.

(75) The walls and ceiling of the battery room, rewind room, motor generator room, toilet and all other rooms should be painted a light color, preferably cream or buff. The first four feet above the floor should be a dark color, which won't show finger marks and other discolorations.

Port Fire Shutters

(76) All port fire shutters should be of about No. 10 gauge iron. Consult your local fire authorities for any special ordinances on this subject.

A fire in the projection room seldom does any extensive damage. (77) It is the sight of smoke by the audience that starts all the trouble. (78) The real purpose of port shutters is not so much to confine the actual fire, as it is to prevent theatre patrons knowing that there is any fire—to keep the smoke as well as the blaze entirely from their view.

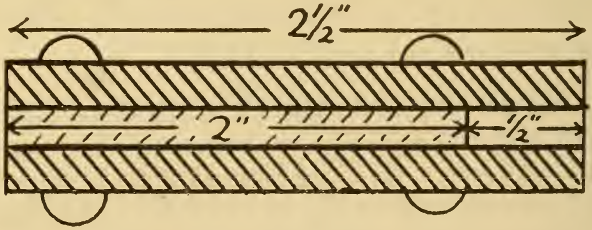

Figure 144

(79) Shutter grooves should therefore be made to fit the shutters snugly but without danger of sticking. The grooves should be mounted level on the wall. They should be not less than one-half inch deep, allowing the shutter one-eighth inch clearance on either side when moving up and down.

Grooves may be made by using the three pieces of scrap iron as shown in Fig. 144, each ⅛ of an inch thick. The three pieces are riveted together, and bolted to a level space on the wall.

The bottom crosspiece is made in the same way but its groove is one inch deep with (80) a strip of soft, fireproof material laid in it to deaden the noise when the shutter is dropped. (81) It is possible to purchase ready-made metal port casing already provided with shutter grooves and a groove for the cover glass of the observation port. These casings are adjustable for different wall thicknesses. Their use is recommended though hand-made jobs are also satisfactory.

Shutter Suspension

The chief service of the shutter is to prevent audiences from recognizing fire. To do this successfully the shutters must drop quietly within two or three seconds after the fire starts. The idea of placing metallic fuse links near the ceiling is correct theoretically, but it does not always work out well in practice, especially if the fire produces plenty of smoke but very little heat.

(82) To be sure of a quick-acting shutter it is essential that a quick-action fuse be installed where the flames will reach it the instant a fire blazes up. This is a very important precaution since a delay, even if measured in fractions of a second, may provoke considerable harm.

(83) No unusual powers of reasoning are required to understand that a metallic fuse is almost totally useless for prompt action where a film fire is confined to a closed projector magazine, from which it exudes relatively little heat but an enormous volume of smoke.

It is wholly useless if it is located at any considerable distance from the magazine. Its location on the ceiling does not lessen its ineffectiveness. As soon as a fire starts, projectionists must attend to closing the shutters at once. It is a moment when life must be considered as more important than property.

Glass in Ports

(84) Since the advent of sound it has become necessary to confine all noises incident to projection to the projection room itself. (85) Optical glass is used to cover ports but optical glass is relatively expensive

and often good plate glass will serve as efficiently.

Optical glass should be used for the projector and stereopticon lens ports, but is not necessary for either observation or spotlight ports. Good plate glass will not distort either vision or a spotlight beam. It probably has minute bubbles or stresses that might visibly affect the projector light beam but it would have no appreciably bad effect when used in stereopticon or effect projector lens ports.

Optical glass, therefore, is recommended for the projector lens ports and if preferred for the stereopticon and effect projector lens ports. For observation and spot lamp ports we recommend the use of a good grade of plate glass.

(86) Be careful that the projectionist's line of vision when he is standing beside the projector is not obstructed by light reflected from the surface of the cover glass over the ports. This can be avoided by setting the glass at an angle. The angle will vary according to the conditions of each projection room; therefore no fixed angle from the perpendicular can be named.

(87) The glass in all ports must be mounted to make the outer surfaces conveniently accessible for cleaning —an important item that must not be overlooked. This may be accomplished in one of several ways. The glass may be mounted in a metal frame and this, in turn, mounted in a second metal frame to be hung on the wall; the frame holding the glass is hinged to the bottom of the wall frame, so that its top may be pulled back and the glass cleaned conveniently. Or the glasses may be set in grooves, except for one objectionable feature: the glass is subject to frequent breakage because it is handled so much.

Lens Ports

We do not favor covering the lens ports with glass unless tests prove it to be really necessary. (88) If the lens ports are reduced to approximately the dimensions of the light beam the openings will be so small that no sound passing through them will annoy any in the audience except perhaps the few who sit close to the ports. The method of reduction is illustrated in Fig. 141.

To make sure, sit in the seats nearest the open ports during performances. If there is not enough noise to annoy you, it will not bother anyone else. (89) Keep the lens ports open if possible—you will eliminate loss of light through reflection from both surfaces of the glass cover, and glass can never be perfectly cleaned—a faint finger mark may spoil an otherwise splendid projection. Lens ports can be open during performances of small attendance.

PROJECTION ROOM ENTRANCE

Entrance to the projection room should be comfortable and convenient. If a stairway is necessary it should be of normal grade and safety. The day of mounting a perpendicular ladder, or climbing into the projection room through a hole in the floor is decidedly past and local building safety regulations should be invoked to force a change, if necessary.

(90) The door should be of ordinary height and in no case less than thirty inches clear width when it is open. (91) If the main entrance of the projection room leads directly into the auditorium then there should be two doors, with not less than three feet between them to form a hallway. Among other advantages this hallway is one more protective factor, in the event of fire, to keep the audience in blissful ignorance of the trouble until it has filed out.

(92) All projection room doors must be fireproofed. There is a door approved by the Underwriters for such use. It is known as the "Kalamein," of which there are two kinds. Use only the one bearing the Underwriters' label, as it influences insurance rates. This door is made of layers of white pine covered with metal.

The Society of Motion Picture Engineers' recommendations call for two exits—at opposite ends of the projection room.

INSTRUMENT BOARD

It is a serious error to use the various ammeters, voltmeters and other controlling gadgets in diminutive form. All meters should be big enough to be plainly visible and should be placed on a panel board located immediately beside the observation ports within easy view of the projectionist. Their dials should be dead black in color (non-gloss); the figures, division marks and needles in white.

What Constitutes a Good Projection Room

(93) The following qualities are essential to any comfortable, well-planned projection room:

Located so that a point midway between the two motion picture projector lenses will be equi-distant from a line at right angles to the screen center.

So located, as to vertical height, that distortion will not increase picture height in excess of five per cent of normal height.

So located that the projection lens E.F. will not exceed four and a half inches E. F. minimum and seven inches E. F. maximum.

Thoroughly fireproof so as to confine fire within its own walls.

All port shutters capable of closing automatically within three seconds of inception of fire at either the projector aperture, film storage reservoir or rewinder.

Port fire shutters to allow either instantaneous manual or automatic operation.

Provision to pump out smoke and gases rapidly enough to maintain a slight vacuum in the room, so that no smoke escapes through crevices into the auditorium.

The floor must be wholly vibrationless.

All illumination to be behind the projectionist as he stands beside the projectors.

No light to be openly visible except when direct light is necessary in case of trouble.

There should be a separate light circuit for brilliantly lighting the room in time of trouble, and one or more reel-lights for use in working around machinery. The front wall should be painted flat black. Next in efficiency is a non-reflecting color, such as green or brown.

The fresh air inlet must be connected either with the theatre ventilation fresh air inlet, or directly with the open air.

Proper steel cabinets for tools and projectionists' clothing should be provided.

All switches and apparatus should be within easy reach of the projectionist.

Observation ports should be large enough to give the projectionist a clear, unobstructed view of the screen.

Sanitary necessities such as a toilet with running water and a wash basin with running water (both hot and cold if possible) should be arranged close to the projection room. A shower may well be added, and a first-aid medicine cabinet as well.

Telephone connection to manager's office and other points about the theatre.

PROJECTION ROOMS IN VERY SMALL THEATRES

(94) Plans for projection rooms in theatres so very small that they cannot conceivably afford to meet the standards above described have been repeatedly discussed by projection authorities, although at the time this is written no general agreement has been reached. Dimensions proposed are 10′ x 7′ x 7′, leaving only 24 inches clearance behind the projectors. It is proposed to install the projectors only 4′ apart (center to center), which would leave a working space of 30″ between them, except when one lamphouse door is opened. At that time the clearance would be only 20″. Such proposals provide for only one exit from the projection room, but still insist unequivocally on stairs and no ladder; they insist also on adequate ventilation, and on approval of all details by the local, city or state authorities.

THE LIGHT SOURCE

Practical Questions

(For answer to each question see statement of corresponding number in Chapter XIV)

1. What two light sources are employed in projection?
2. Is there a wide variation in available arc light sources?
3. Is special treatment of each arc light source essential to best results?
4. How is an electric arc formed?
5. What becomes of the carbon particles?
6. How is a conductor established between the incandescent carbon tips?
7. What is the "crater" of an electric arc? How is it formed?
8. What is the temperature of the crater floor?
9. How does an electric arc crater floor compare in brilliancy with other light sources?
10. How can the brilliancy be further increased?

CARBONS, PAGE 361

11. What is a "carbon"? How are carbons classified?
12. What qualities must projection carbons possess?
13. Do carbon cores contain chemicals?
14. Must carbons be free from moisture when used?
15. For what reasons was carbon selected as the base of electric arc electrodes?
16. At what temperature is carbon volatilized—transformed into gas?
17. What is the luminosity of carbon at the temperature of volatilization?
18. Does the conductivity of carbon increase as temperature is increased?
19. Is carbon core conductivity higher than that of the surrounding shell?
20. Are carbons made in all lengths required for arc lamps?
21. Describe the general process of making a carbon.
22. What is the source of the most intense light in each of the three general types of projection arcs?

23. What effect will impurities in a carbon have on illumination?
24. What are the harmful effects of moisture?
25. Where should carbons be stored?
26. How many spare carbons should be carried in stock?
27. What precautions should be taken when the theatre changes its brand of carbons?
28. Is it essential that the carbons match the amperage?
29. What will be the effect of an oversized positive carbon?
30. What are the advantages of a small negative carbon tip?
31. What is meant by a carbon "spindling"? May it occur to both carbons simultaneously?
32. What causes spindling?
33. If your carbons are not overloaded but spindle, what is the first thing that demands your attention?
34. State the effect of positive carbon spindling. Of negative carbon spindling. What is "penciling"?
35. Does spindling tend to injure the metal parts of high intensity lamps?

INSPECTION OF CARBONS, PAGE 368

36. What requires special attention in newly purchased carbons?
37. What is important in regard to carbon cores?
38. Are small cracks running lengthwise in low intensity carbons harmful?
39. What about circumferential cracks?
40. What are carbon savers and what is the advantage of using them?
41. What is a mushroom tip and what causes it?
42. Do properly stored carbons suffer any harm because of age?

PROPER CARBON COMBINATIONS, PAGE 370

43. What size carbons must be used for different types of equipment of all amperages?
44. Why are optical devices included in the carbon arc lamp?
45. Why is a carbon "feeding" mechanism necessary?
46. What is meant by "striking the arc"?
47. What is a "dowser"?
48. What are the requirements of the arc lamp with respect to ventilation?

49. Why should arc gases be vented outside the projection room?
50. What is a carbon "jaw"?
51. Why are magnets used in connection with the arc lamp?
52. What are mirror guards and why are they used?
53. What special condition in an arc lamp complicates the choice of lubricants?
54. How can the projectionist tell if his arc is correctly positioned?
55. How can the projectionist tell if his arc current is what it should be?
56. What types of current are used in projection arcs, and from what sources are they obtained?
57. What is a straight high intensity light source?
58. What is the brilliancy of straight high intensity craters per square mm?
59. Why should the straight high intensity light source be operated carefully?
60. Is high intensity very sensitive to improper adjustment?
61. What is the total candle power of high intensity at different amperages?
62. What is the correct adjustment of the high intensity arc?
63. Is arc voltage a safe guide in operating the high intensity light source?
64. From what does the major portion of high intensity light emanate?
65. Is high intensity light more brilliant than carbon at the temperature of volatilization?
66. Must the high intensity crater be kept filled with gas?
67. By what is the gas confined to the positive crater?
68. In exactly what position should the negative carbon tip be?
69. What are the correct measurements between positive and negative carbon tips with a 16 mm trim?
70. Do the various makes of high intensity lamps all perform the same functions?

HIGH INTENSITY POSITIVE CONTACTS, PAGE 378

71. Of what are high intensity lamp carbon contacts made and how long should they last?
72. What should be done with badly burned or pitted contacts?
73. Is it practical to use a file on the contacts?

74. Describe the best method of cleaning positive contacts.
75. What can be used in place of a bar in the cleaning process?
76. How can a minor swelling on the face of the contact be smoothed off?
77. What forms on the face of a high intensity contact and what will happen if it be not cleaned off frequently?
78. How often should high intensity contacts be cleaned?
79. Should spare contacts be carried in stock?

Positive Carbon Rotation and Feed Unit, page 381

80. Is the positive carbon rotated and fed forward by the same element?
81. Must moving high intensity lamp parts be lubricated? With what?

When Positive Carbon Fails to Feed Forward, page 381

82. When the positive carbon fails to feed forward what is the trouble?
83. How much tension should the feeding mechanism apply to the carbon?
84. What may result from too much or too little tension?
85. What should be done if the positive carbon ceases to rotate or feed forward?
86. How do you make a quick test for roughness of contact or for excessive contact tension?

High Intensity Carbon Contact Pressure, page 382

87. What does improper contact pressure cause?
88. Must the contact pressure have careful, constant attention?
89. Should spare feeding mechanism parts always be kept in stock?

The Flame Shield, page 383

90. What is a flame shield and what is its purpose?
91. What attention does the hole in the flame shield require?
92. What should be done each day before the performance begins?
93. Should a high intensity lamp be operated without a flame shield?

94. What is the negative head?
95. How must the negative head be adjusted?
96. Describe the negative head current carrying contact.
97. How should the negative carbon bear upon the groove or grooves?
98. Must care be taken to position the negative carbon properly?
99. What is important in regard to the negative head?
100. What other items must be watched in the high intensity arcs?
101. What is the effect of burning the high intensity carbon below or above its rated capacity?

SPEED OF CARBON CONSUMPTION, PAGE 384

102. What is the burning rate of the 9 and the 13.6 mm high intensity trim?
103. Why should you know the exact consumption speed of the carbons you employ, regardless of what type lamp you are using?
104. How can you calculate carbon consumption speed?
105. Is an ammeter a necessity?
106. What are the harmful results of inadequate lamphouse ventilation?
107. How much lamphouse ventilation should be maintained?
108. Why should the dowser be closed when striking the arc?
109. What should be done after running each reel?

REFLECTOR TYPE HIGH INTENSITY LAMPS, PAGE 385

110. Are the straight high intensity arc and reflector type high intensity the same?
111. What is the amperage range for the reflector high intensity arc?

LOW INTENSITY LIGHT SOURCE, PAGE 386

112. Does the reflector type low intensity arc supply substantial light values?
113. Why is this true?
114. Does the total light production power vary and for what reasons?

115. What is the candle power of the low intensity arc per square mm of crater floor area?
116. How much may the amperage vary?
117. What is the average increase in the crater area for each added ampere of current?
118. Is brilliancy of the carbon core uniform?
119. What elements demand constant attention when low intensity, reflector type light sources are employed?
120. How is the condition of wires inside the lamphouse determined?
121. What attention does the mirror require?
122. How are mirrors cleaned?
123. Describe how to fix the right distance of the arc from the mirror.
124. What lubricant should be used in the lamp?
125. Give a short summary of the necessary operating conditions for the old style d. c. arc.

LOW AMPERAGE NON-ROTATING H.I. ARCS, PAGE 390

126. What were the two major types of projection arc light sources on which theatres were forced to rely until recently?
127. What is the effect of high and low electrode current density upon light source brilliancy per unit area?
128. How does the non-rotating high intensity carbon differ from other light sources?
129. What elements in light sources are important in considering screen illumination values?
130. What are the chief characteristics of the high intensity arc?
131. Before the non-rotating carbon what was the smallest carbon diameter available? How many amperes did it require for satisfactory operation?
132. What is the chief similarity between the non-rotating H.I. carbon and the larger diameter high intensity light source?
133. What other factors of the non-rotating carbon make it extremely efficient?
134. What is the importance of the gas stream in all high intensity arcs?
135. How does the position of the negative and positive carbons affect the gas stream?
136. Must the carbons be precisely in line with each other sidewise?

137. Do extreme air drafts disturb this type of arc?
138. How can the arc be protected against air currents set up by the rear shutter?
139. Can Suprex carbons be underloaded or overloaded without affecting their efficiency?
140. What is the relative efficiency of the 8 mm and the 7 mm trim?
141. How many light tones are there in high intensity light sources?
142. What conditions the tone of light that reaches the screen?
143. Is correct adjustment of the arc control very important?
144. What development in carbons made possible the one-kilowatt high intensity lamp?
145. Why are some lamps built with separate mechanisms for controlling positive and negative carbon feed?
146. What drives the carbon feed mechanism?
147. Describe a non-rotating positive carbon high intensity lamp.
148. At what frequency is the projection screen illuminated?
149. How is it that an arc can be formed and maintained by alternating current?
150. Why is 96-cycle current generated for use with one type of a.c. arc?
151. Using a 96-cycle arc, need shutter action and current frequency be in phase? Explain.
152. Are both line frequency and 96-cycle a.c. used with the same lamp? Why?
153. Will instructions obtained from the lamphouse manufacturer, and from the carbon manufacturer, agree?
154. Can the location of the arc in the lamp, and the length of the arc gap, be controlled by the projectionist?
155. Is accurate optical adjustment of the arc lamp important?
156. What harm will result if the arc is optically misadjusted?
157. Where can the projectionist obtain complete information on the mechanical details of a given make and model arc lamp?
158. Where can the projectionist obtain complete information on the operation, adjustment and maintenance of a given make and model arc lamp?
159. Why must optical surfaces of the arc lamp be kept scrupulously clean?
160. With what should they be cleaned?
161. Is a cotton cloth suitable for cleaning optical surfaces?
162. How often is the floor of the lamphouse cleaned?

163. If the carbon feed relay or carbon feed motor introduce noise into the sound, and cleaning does not help, what should be done?

THE FILAMENT PROJECTION LAMP, PAGE 403

164. What advantage does the filament lamp light source possess?
165. How does the filament lamp light source compare with other sources of motion picture light?
166. What is the character of filament lamp screen illumination?
167. Does the filament lamp change the appearance of color pictures?
168. Should projectionists handling the filament projection lamp know its peculiarities?
169. In what way does the filament lamp produce light?
170. Of what is the filament made? What property enables it to produce the highest illumination of all other light sources save the electric arc?
171. With what are filament bulbs filled. What is its effect?
172. What is the useful life of the filament projection lamp?
173. What are the characteristics of the monoplane type of filament projection lamp?
174. What are the advantages of the biplane type of filament?
175. What governs the voltage that may be applied to a filament?
176. Why is the low voltage lamp used rather than the 115-volt lamp?
177. Why is the distance between collector and light source important?
178. What advantage is there in the tall bulb?
179. Can a filament lamp be made to operate successfully at either constant current or constant voltage?
180. What happens when the filament burns away?
181. How may deposits in the interior of filament bulbs be removed?
182. Is constant voltage and current flow necessary to good operation?
183. What governs a filament lamp's powers of screen illumination?
184. Is a filament lamp's power affected by inexact alignment of parts?
185. What should be done if the filament sags?
186. Should the full operating load of current be switched directly on a cold filament?

187. What provision is made for warming the lamp up?
188. Upon what is the size (area) of a light source dependent?
189. Has a light source diameter greater than one-half inch any screen illumination value?

THE MIRROR REFLECTOR, PAGE 409

190. What does the mirror used with filament lamps do?
191. How is the mirror located with relation to a monoplane filament lamp?
192. What is the advantage of careful positioning of the mirror?
193. Is it efficient to couple a spherical mirror with a biplane lamp?
194. How is the spherical mirror correctly located?
195. Is the use of a mirror with a filament lamp advisable?

CONDENSING LENSES, PAGE 41

196. What is the function of the condenser?
197. Why must the light source be as close as possible to the collector lens?
198. What is the chief value of the prismatic or aspheric condenser?
199. What type of condenser do the newer types of filament lamp employ?
200. What kind of surfaces do aspheric condensers have?
201. Through what angle will the aspheric condenser pick up light efficiently?
202. Are aspheric condensers needed for lantern slide projection?

THE PROJECTION LENS, PAGE 43

203. Does the filament lamp light beam diverge rapidly between aperture and projection lens?
204. What projection lenses must be used where the E.F. falls below 4.5 inches?
205. Should No. 2 size projection lens be used when the E.F. is in excess of 4.5 inches?

CHAPTER XIV

THE LIGHT SOURCE

The light source is a subject of very great importance, since it is the base upon which excellence in projection rests.

(1) At present there are only two sources of light available for projection: the electric arc and filament lamps. (2) There are several varieties of the electric arc, each of which is different from all other arcs used for projection and (3) each requires different treatment for production of the maximum quantity and quality of light.

(4) The electric arc is formed by charging two carbon rods at opposite polarities of E.M.F. from same power source, bringing the ends or tips together, and again separating them. (5) Physical contact results in the flow of current which heats the carbon particles until they are "volatilized," that is, transformed into gases. (6) These gases form a low-resistance conductor between the positive and negative carbon tips over which current flows. (7) By the action of the heat engendered by the current, a saucer shaped depression is formed on the tip of the positive carbon (called the crater), the bottom or "floor" of which is, in (8) the straight carbon arc, heated approximately to 3,500 degrees Centigrade, about equal to 6,300 degrees Fahrenheit. (9) Except for the high intensity arc this is the highest brilliancy obtainable by heating any known solid substance. (10) It is possible to secure higher brilliancy by combining chemicals with carbon, as will be explained later on in this discussion of projection light sources.

CARBONS

(11) The carbon rods, between the tips of which the

arc is formed, are called carbons, although they contain other materials beside carbon, and are often copper-coated. Carbons are classified by trade names, by their length, and by their diameters. Carbon diameters are very often stated in millimeters (mm). One mm is 0.03937 of an inch, hence millimeters may be reduced to inches by multiplying the mm diameter by 0.03937. Thus a 12 mm carbon would be $12 \times 0.03937 = .47244$, or about one-half of an inch in diameter.

Carbons used in modern motion picture projection work must have certain well-defined qualities. (12) They must, within very narrow limits, be straight, uniform in texture and, except for the core, of uniform density throughout. They must, to all intents and purposes, be entirely free from impurities. They must, within very narrow limits, be made in exact diameters, each diameter suited to a given range of current flow. (13) Their cores must contain certain materials, some of them chemically rare, the exact composition of which is determined by the uses to which the carbon is to be put. (14) Carbons must be free from all moisture at the time they are used or results will not be the best.

(15) Carbon was selected as the base for arc lamp electrodes because it is the one available material able to withstand the action of heat up to (16) approximately 3,500 degrees Centigrade, at which point it is finally "volatilized," that is, transformed into gases except for a very small residue of ash. (17) At such temperature it is very brilliant. In fact the luminosity produced is second only to that of the sun itself. Carbon may be reduced to a very fine powder, mixed with available, relatively cheap binders and moulded into rods of exact diameter having sufficient strength and rigidity to serve all the needs of practical projection work.

(18) In the form of finished rods, carbon possesses fair conductivity which, contrary to the action of metallic conductors, increases as its temperature is increased.

(19) In the process of manufacture a central opening of required shape and diameter is provided, later filled in with a core mixture of such nature that the core conduc-

tivity is much higher than that of the carbon shell. The purpose of the core is to steady the arc and hold it in a fixed central position; also in the core certain materials, "rare earth" metals, are intermixed, and they serve to whiten or otherwise alter the color or tone of the light, and serve other useful ends.

(20) Carbon rods are made in all lengths and diameters which projection practice demands. They are relatively inexpensive.

(21) The carbon, except for its central core, is composed entirely of carbon powder very similar to the product known to us as "lampblack." This powder having first been subjected to the action of powerful magnets to remove metallic impurities, and put through other purifying processes, is thoroughly mixed with a binder of pure pitch. The resultant "dough" is then forced, under very heavy pressure, through a round role in the center of a steel plate or "die," the diameter of which corresponds to the diameter of the carbon it is desired to make. If a cored carbon is to be made, a steel needle is fixed in the center of the opening in the die, so that a hole is left in the carbon rod. The carbon comes from the die in the form of a continuous rod, which is afterward cut into proper lengths and subjected to a baking process in ovens or kilns. Baking reduces the pitch binder to carbon. After cooling the rods are removed and the core, if it is to be a cored carbon, is forced in under very high pressure.

The rods are then baked again to reduce the core to the necessary condition; they are cleaned, tested for straightness and possible defects, cut to proper lengths, pointed, and, after inspection, packed for shipment.

We have outlined very roughly the process of manufacture. There is very much more to it, such as the inspection and testing of materials at various stages, etc. It is impractical to set forth the many elements that enter into carbon cores. They are, for the most part, either patented or well guarded trade secrets, promulgation of which would serve no useful purpose so far as concerns the projectionist.

The carbon rod surrounding the core (where there is a core) provides most of the crater floor area. The core serves several purposes as already indicated but in addition the various chemical elements with which it is impregnated make it either a high or low intensity carbon, or any one of several other sorts, including White Flame and a.c. carbons.

(22) The source of the most intense light varies in different types of arcs. There are three general types. In the low intensity arc (which is essentially obsolete but still has not been replaced in many theatres) the crater of the positive carbon is the light source; the carbon there being at or near the point of volatilizing into gas. In the so-called flame arc, the arc itself, made more luminescent by the inclusion of rare earth materials in the carbon core, is the essential source of light, the incandescence of the carbons being unimportant in comparison. In the high intensity arc, the combination of rare earths in the carbon core and a greater current density (more amperes in proportion to crater diameter) creates a relatively deep crater; the floor of this crater contains a concentration of rare earth materials that have been volatilized and are in gaseous form; these concentrated gases, plus the crater surface itself, are the principal sources of high intensity light.

(23) It is essential to good results that the entire area of the crater floor have, as nearly as possible, an even temperature, which gives a uniform luminosity. This can be accomplished only by the use of very pure carbon materials. Should impurity occur at any point, or carbon density vary at different points of the crater floor, there will be a variation in the resistance to the current; as a result current flow and luminosity will not remain constant until the fault, whatever it be, has burned away. This being self evident, we may readily understand the importance of pure materials and of good mixture to provide uniform density of the carbons at every point.

With high intensity the source of light, as said, is very largely the highly luminous gas or vapor contained in the positive carbon crater and held therein by the negative gas stream. This in no degree lessens the necessity for evenness of resistance at all points of the crater floor, excepting only the difference inherent between the core and surrounding carbon.

EFFECT OF MOISTURE

(24) Best results cannot be had from carbons impregnated with moisture. Under the action of heat moisture will be converted into steam, which, because it cannot be instantly expelled, will set up high pressures at points within the body of the carbon and create a very harmful situation. Minute particles will blow off from the crater floor causing the light to flicker.

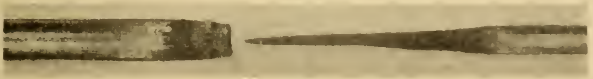

FIG. 145—Effects of overloading a negative carbon. It gives a poor light because it is badly "spindled."

This is what is often called "sputtering of the arc." It is most in evidence when the moisture is contained in the positive carbon, though the effect may, in lesser degree, be produced from moisture in the negative.

(25) Carbons should be kept in a warm, dry place for several days before they are used. (26) Two or three bundles of carbons of all types and sizes should be kept constantly in stock, stored in the warmest, driest place available. It is a good plan to lay in a three months' supply, replenishing the stock every thirty days thereafter, always using those longest in stock.

(27) We suggest that before purchasing any carbons newly marketed, the projectionist obtain a small number of the right diameters for a trial in his own theatre. If they seem to work well, it is safe to purchase a full bundle of positives and negatives to try them out thoroughly.

HIGH INTENSITY CARBONS

High intensity carbons differ but little if at all from other kinds as regards the material composition of their body or shell. The materials in the core of a carbon differ widely from those composing its shell, the exact composition being largely a trade secret. Rare earth metals, including cerium, lanthanum, neodymium and praseodymium may be used in varying proportions. Very naturally carbon manufacturers do not disclose their formulas, but such knowledge is of no practical value to projectionists. The high intensity arc is treated more fully later in this chapter.

Effect of Carbon Diameters

(28) To secure best results in projection the capacity of the carbons must be very carefully matched with the amperage. (29) If the positive carbon is too large in diameter the arc will be inclined to unsteadiness. If the negative is too large there will be undue interference by the unnecessarily large tip, which means waste of light.

While it is quite true that carbons of excessive current capacity make it unnecessary to trim the lamp so often, and may even save a bit in carbon cost, such saving nevertheless represents very poor practice. It results in an unsteady light of relatively poor quality, and at such a price any small saving in carbon cost is an absurdity. Any projectionist worthy of his hire will select and use only carbons of a kind and diameter in combinations recommended by the carbon manufacturer for the amperage and type of light source he is using.

(30) Keeping within range of proper current capacity, the smaller the negative carbon the smaller will be its tip and consequently the less light it will obstruct and waste; also, if the negative tip be unnecessarily large it encourages a tendency in the arc to be unsteady and to "travel," producing light fluctuations which are revealed on the screen.

Use the smallest negative carbon possible without inducing spindling but remember that the carbon makers have set up limitations which should be strictly adhered to. Copper coating aids materially in diameter reduction.

CARBON SPINDLING

(31) "Spindling" means the burning of a carbon tip to an abnormally long, slim point as illustrated in Fig. 145. It may occur to either or both positive and negative. It is an exceedingly bad condition making for poor light and waste of power. (32) It may be due to overloading—using amperage above the rated capacity of the carbons. It may be caused by lack of proper firm contact between the carbon and carbon jaw over the entire area of the contact surface, which in turn may be due to (a) loose contact, (b) roughened or pitted carbon jaw; (c) dirty contact surface, or (d) in some cases by current entering the carbon too far from the carbon tip. This last seldom happens except in high intensity lamps where the carbons are working above their rated capacity. Whatever its cause, it will be aided materially by high temperatures in poorly ventilated lamphouses.

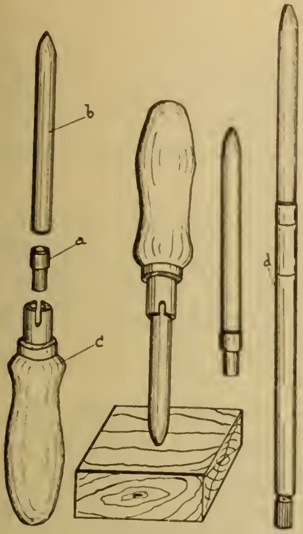

FIGURE 146

(33) If your carbons seem inclined to spindle and yet are not being forced above their rated capacity, first make sure that the lamphouse has proper and continuous ventilation. Examine the carbon jaws, making sure they are clean, not pitted, and that when tightened up they clamp the carbon firmly through their entire area.

(34) The net effect of spindling of the positive carbon is a reduction of the light source area and a reduction of the current flow due to the increased resistance offered by the small spindling part of the carbon. The penciling of the negative carbon by increasing the resistance, decreases the amperage flow, and so decreases screen illumination. Spindling may or may not cause an unsteady

arc. Another term for spindling is "penciling."

(35) In high intensity arcs the metallic parts of the lamps are close to the very hot light source, and here spindling may do damage.

Inspection of Carbons

(36) Newly purchased carbons should be examined carefully. Inspect the core ends, which should, in each carbon, fill the opening completely. There should be no defects, though an occasional small fault need not cause rejection of a bundle of carbons.

(37) It is manifestly essential to steady light production that carbon cores be continuous, and that they fill their space completely, adhering to its walls tightly. Otherwise short sections may drop out as the carbon is consumed, with disastrous effect upon the screen illumination.

(38) No attention need be paid to small cracks running lengthwise in low intensity carbons. They do no particular harm and are, in a manner, characteristic of the product. It is extremely unlikely that any crack will be found so wide or deep as to cause trouble.

(39) Narrow and shallow cracks around low intensity carbons should be tolerated but circumferential cracks of more than superficial depth may cause a carbon to break while in use. Cracks of any sort in high intensity carbons are a cause for rejection. They are very detrimental to screen illumination. It may be assumed safely, however that all carbon manufacturers compel a severe inspection of their product before it leaves the factory.

Using Carbon Stubs

(40) Although projectionists should burn their carbons as short as possible, it is questionable economy to attempt to make use of carbon stubs by joining them more or less imperfectly to whole carbons or other carbon stubs. Several devices, however, have been perfected to permit joining, or burning shorter stubs than would otherwise be possible. These devices, called "carbon

savers," having come into wide-spread use, and effect true economy. One type is illustrated on Fig. 146. The process of using them is as follows: A cap is slipped on the rear (unburned) end of the stub. The other end of the cap then is shoved into the recess in upper end of handle c. The end of the stub is then rested on the wooden block, which must be of soft wood to prevent breaking the crater edges, and the upper end of the handle is struck a sharp blow with the palm of the hand. This not only shoves the cap tightly on the carbon end, but clamps it there immovably and in good electrical contact. The handle then is pulled off and the cap inserted in a recess in the end of rod d, and a knurled nut at its bottom is turned clockwise, which clamps the cap tightly into the rod. The rod in turn is inserted into the carbon jaws of the arc lamp. Such devices save as much as 25 per cent of the carbon.

Another way to provide for maximum use of carbons is to use specially processed carbons having a hole drilled into one end, and a pin milled at the other to fit into the hole. When a carbon is burned down several inches, a new carbon can be attached to it by this male-and-female means, the stub forming the tip of the new carbon; and over the joint is placed a copper sleeve, which is comparable to the regular copper coating and burns away.

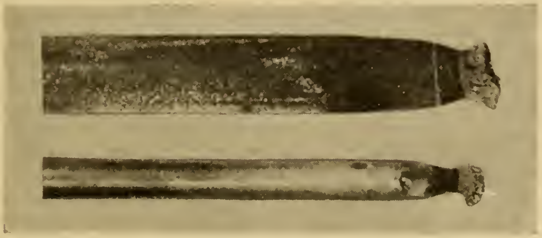

FIGURE 147

MUSHROOM POINTS

(41) What is known as a "mushroom" carbon tip is illustrated in Fig. 147, in which a mushroom appears on a positive (at the top) and a negative (at the bottom).

It is caused by burning an arc too short. The only remedy is to carry a longer arc.

Carbons Do Not Deteriorate

(42) Carbons, properly stored, will be just as good ten years after storage as when made, provided they have absorbed no moisture. If they have, after a thorough drying out, they will be as good as ever. Store them, if possible near the ceiling of the projection room, where they will dry out thoroughly.

(43) Proper Carbon Combinations:

The following carbon sizes and combinations are those officially approved for National carbons. For carbons of other manufacture this information can be secured directly from the distributor.

D.C. MIRROR OR REFLECTOR ARC LAMPS
(Angular Trim Lamps)

AMP.	POLARITY	SIZE and KIND
6-10	Positive	9/mm x 8″ Cored Projector
	Negative	8/mm x 8″ Cored Projector
11-15	Positive	10/mm x 8″ Cored Projector
	Negative	9/mm x 8″ Cored Projector
16-20	Positive	12/mm x 8″ Cored Projector
	Negative	10/mm x 8″ Cored Projector

D.C. MIRROR OR REFLECTOR ARC LAMPS
(Horizontal Trim Lamps)

AMP.	VOLT.	POLARITY	SIZE and KIND
10-15	54-57	Positive	9/mm x 8″ Cored Projector
		Negative	6.4/mm x 8″ Solid Projector
16-20	54-57	Positive	10/mm x 8″ Cored Projector
		Negative	7/mm x 8″ Solid or Cored Projector
21-25	54-57	Positive	12/mm x 8″ Cored Projector
		Negative	8/mm x 8″ Solid or Cored Projector
26-30	54-57	Positive	13/mm x 8″ Cored Projector
		Negative	9/mm x 8″ Cored Projector
31-35	54-57	Positive	14/mm x 8″ Cored Projector
		Negative	10/mm x 8″ Cored Projector

NOTE: SRA carbons were discontinued by their manufacturer in 1942. Old type low intensity carbons thereupon took the place of the SRA type.

HIGH-INTENSITY ARC—DIRECT CURRENT

AMP.	VOLT.	POSITIVE	NEGATIVE
75-90	54-60	11/mm x 20″ H.I. Proj.	11/32″ (or ⅜″) x 9″ Orotip Cored
120-130	67-69	13.6/mm x 22″ H.I. Proj.	⅜″ (or 7/16″) x 9″ Orotip Cored
140-160	70-72	16/mm x 20″ H.I. Proj.	7/16″ x 9″ Orotip Cored (extra heavy coated)

HIGH-INTENSITY REFLECTOR ARC—DIRECT CURRENT

AMP.	VOLT.	POSITIVE	NEGATIVE
60-85	48-58	9/mm x 20″ Hi-Lo Proj.	5/16″ x 6″ (or 9″) Orotip Cored

SUPREX CARBON COMBINATIONS

AMP.	VOLT.	POLARITY	SIZE and KIND
32-40	31-40	Positive	6/mm x 12″ Cored Suprex
		Negative	5/mm x 9″ Solid Suprex
42-50	31-40	Positive	7/mm x 12″ Cored Suprex
		Negative	6/mm x 9″ Cored Suprex
56-65	31-40	Positive	8/mm x 12″ Cored Suprex
		Negative	6.5 (or 7/mm) x 9″ Cored Suprex

A.C. ARC ON 96-CYCLE SUPPLY

AMP.	VOLT.	SIZE and KIND
52-66	18-22	7/mm x 14″ Copper-Coated H. I. Positive and Negative

COPPER-COATED A.C. HIGH-INTENSITY CARBONS

AMP.	VOLT.	SIZE
40-45	22-25	6/mm x 10″
60-65	23-26	7/mm x 12″
75-80	24-29	8/mm x 12″

D.C. OLD TYPE, LOW-INTENSITY LAMPS

AMP	VOLT.	POLARITY	SIZE and KIND
25-50	51-56	Positive	⅝″ x 12″ Cored Projector
		Negative	5/16″ x 6″ Orotip Solid or Cored Proj.
50-65	56-59	Positive	¾″ x 12″ Cored Projector
		Negative	11/32″ x 6″ Orotip Solid or Cored Proj.
65-70	59-60	Positive	⅞″ x 12″ Cored Projector
		Negative	11/32″ x 6″ Orotip Solid or Cored Proj.
70-85	60-63	Positive	⅞″ x 12″ Cored Projector
		Negative	⅜″ x 6″ Orotip Solid or Cored Projector
85-120	63-68	Positive	1″ x 12′ Cored Projector
		Negative	7/16″ x 6″ Orotip Cored Projector
120-140	68-70	Positive	1⅛″ x 12″ Cored Projector
		Negative	½″ x 6″ Orotip Cored Projector

D.C. LOW-INTENSITY SPOT AND FLOOD LAMPS

AMP.	VOLT.	POLARITY	SIZE and KIND
30-40	52-54	Positive	⅝″ x 12″ Cored
		Negative	½″ (or 9/16″) x 6″ Cored
40-50	54-56	Positive	⅝″ x 12″ Cored
		Negative	5/16″ x 6″ Orotip Cored
50-55	56-57	Positive	¾″ x 12″ Cored
		Negative	⅝″x6″, or 5/16″x6″ Orotip Cored
55-65	57-59	Positive	¾″ x 12″ Cored
		Negative	11/32″ x 6″ Orotip Cored
65-70	59-60	Positive	⅞″ x 12″ Cored
		Negative	11/32″ x 6″ Orotip Cored
70-85	60-63	Positive	⅞″ x 12″ Cored
		Negative	⅜″ x 6″ Orotip Cored
85-100	63-66	Positive	1″ x 12″ Cored
		Negative	⅜″ (or 7/16″) x 6″ Orotip Cored

A.C. LOW-INTENSITY SPOT AND FLOOD LAMPS

AMP.	VOLT.	UPPER CARBON	LOWER CARBON
30-60	35	⅝" x 12" W.F.A.C. Proj.	⅝" x 6" W.F.A.C. Proj.
60-80	35	¾" x 12" W.F.A.C. Proj.	¾" x 6" W.F.A.C. Proj.

D.C. HIGH-INTENSITY SPOT AND FLOOD LAMPS

AMP.	VOLT.	POSITIVE CARBON	NEGATIVE CARBON
85-95	58-62	11/mm x 20" H.I. Proj.	11/32" x 9" Orotip Cored
100-110	63-66	13.6/mm x 22" H.I. Proj.	⅜" x 9" Orotip Cored
110-125	66-68	13.6/mm x 22" H.I. Proj.	7/16" x 9" Orotip Cored

WHITE FLAME A.C. PROJECTOR CARBON COMBINATIONS

AMP.	VOLT.	UPPER CARBON	LOWER CARBON
25-40	25-28	½" x 12"	½" x 6"
40-60	28-32	⅝" x 12"	⅝" x 6"
60-75	32-35	¾" x 12"	¾" x 6"
75-100	35-40	⅞" x 12"	⅞" x 6"

H.I. TRIMS USING "VICTORY" CARBONS

Brought out in 1942 for the wartime purpose of conserving copper, this series—called "Victory Carbons"—was given a thinner copper coating than the types they were designed to replace, requiring adjustment of arc current to conform to the ratings. Trim characteristics follow:

TYPE OF LAMP	ARC AMPERAGE	SIZE AND TYPE
"1 Ky" High Intensity. A. C.	52-66	7/mm x 9" H.I., A.C. Carbons in both holders
"1 Ky" High Intensity. D. C.	40-42	7/mm x 12" or 14" "Suprex" positive 6/mm x 9" "Orotip" N Negative
Simplified High Intensity, D. C. with adjustable feed ratio	42-45	7/mm x 12" or 14" "Suprex" Positive 6 mm x 9" "Orotip" N Negative
Simplified High Intensity, D.C. with fixed feed ratio	42-45	7/mm x 12" or 14" "Suprex" Positive 7/mm x 9" "Orotip" C Negative
Simplified High Intensity, D. C.	56-65	8 mm x 12" or 14" "Suprex" positive 7/mm x 9" "Orotip" C Negative

PROJECTION LAMPS

(44) Carbons are burned in a lamp mechanism which includes optical devices for concentrating the maximum possible light at the projector aperture. In most lamps, these devices are focussed upon the crater of the positive carbon.

(45) Because it is necessary to keep the crater of the

positive carbon at the correct point of focus while both carbons are being burned away, all lamps include devices for "feeding" the carbons as fast as they burn, thus keeping the crater of the positive carbon always at the same location, and keeping the arc gap always the same length. In the so-called straight high intensity type of lamp, the mechanism not only feeds the carbons, but rotates the positive so it will burn more evenly.

(46) All lamps have provisions for striking the arc. The term means to bring the tips of the two carbons together, permitting current to flow between them. Spring action quickly separates the carbons to a pre-determined distance. Projectionists know that when a switch in a circuit carrying substantial amperage is opened, there is a tendency toward arcing. Sometimes, if the switch is not opened far enough, an arc will form that will visibly burn away part of the copper contacts. This happens because at the moment the contact is breaking the air ionizes sufficiently to permit some current to flow across the gap; and the current flow creates further ionization. If the switch is opened far enough, the arc will be broken. Since the carbons in an arc lamp are not separated to any great distance, a continuous arc is established, across a gap amounting to a small fraction of an inch. The length of this gap is kept constant, as the carbons burn away, by the action of the feed mechanism.

(47) All arc lamps are equipped with dowsers. The dowser is a movable metal shield which, when "closed," prevents light and heat from reaching the film in the projector aperture. Either the dowser or a separate shield may also be interposed, in "closed" position, between the arc and the optical mirror or condenser. When an arc is first struck, and for a few moments afterward, there may be a strong tendency toward sputtering—very hot, tiny fragments of carbon or copper being thrown in all directions. If these fragments strike the optical elements, they will "pit" or pock mark the glass. Hence the dowser, or a separate movable shield, may be interposed until the arc has steadied, after which comparatively little sputtering occurs. The dowser may be kept

closed until the moment of changeover, and then moved out of the light path automatically in the course of changing over from one projector to another.

(48) All arc lamps are provided with ventilation, either by natural or forced draft. Natural ventilation is provided by the heat of the arc and by openings at the top and bottom of the lamp housing. The upper opening has the form of a very short chimney, to which a vent pipe can be fitted. The heat of the arc draws air in at the lower openings and forces it out at the upper vent. This action is often reinforced by connecting a vent pipe to the chimney, and installing an exhaust blower in the vent pipe system. It is desirable to vent the arc gases outside the projection room. However, too much draft cannot be used; it would cause the arc to become unsteady, resulting in a flickering illumination of the screen.

(49) Arc gases should be vented outside the projection room for two reasons: (a) they are mildly poisonous, although there is no record that any projectionist has ever been seriously harmed by them; and (b) they carry very fine carbon particles which tend to settle as a semi-conducting dust in electrical apparatus. This dust, which is fine enough to seep through the smallest opening, is especially harmful in sound equipment. Venting the arc properly takes the dust outside the projection room.

(50) All lamps include provisions for holding the carbons in correct position, and carrying current to them. The carbons are mounted in metallic holders known as carbon jaws, which in turn are electrically connected to the source of current. In some lamps current is not brought to the carbons through the jaws but through a separate sliding contact. Inserting the carbons in the jaws is called trimming the lamp. The choice of carbons used—the size of carbons, that is—is called the trim of the lamp.

(51) Many lamps are fitted with steel magnets, rigidly and immovably located, which act to steady the arc.

(52) Mirror guards are used in many theatres. They are thin, transparent pieces of curved glass, which fit accurately over the optical mirror. The glass guard re-

ceives such hot particles as the arc may throw toward the mirror from time to time; it is the guard that becomes pitted and must be replaced in due course. The advantage of using mirror guards is that they cost much less than mirrors.

(53) All parts of the lamp are exposed to very high temperatures. Metals used for the carbon jaws and other exposed parts are selected accordingly. Lubricants (where required) must be such as to withstand the arc temperatures.

(54) All lamps are provided with means by which the projectionist can observe the arc while it is burning, and with devices by which he can accurately control the position of the arc in case of any slight misfunctioning of the feed mechanism. Small tinted glass windows are built into the door of the lamphouse. In addition there is often a small mirror or prism, and a marked card. A reflection of the arc is thrown on the marked card. If the arc does not occupy exactly the correct position with reference to the markings the projectionsit adjusts its position by means of the external controls with which every lamp is equipped.

(55) Many, in fact most, lamps are fitted with ammeters, so the projectionist can observe the amount of current he is using. He can adjust the current consumed, within limits, by slightly changing the length of the arc gap, using the external controls of his lamp for that purpose.

(56) D.C. arcs derive their current from (a) a d.c. power line, in which case the voltage is usually reduced by a series resistor known (see page 143) as a ballast resistor; (b) from a motor-generator, or (c) from a rectifier. A.C. arcs are not at present in very widespread use, but there is a type of a.c. arc that is operated at 96 cycles, the current being derived from a special motor-generator. Other types of a.c. arcs may be supplied at line frequency through a transformer.

STRAIGHT HIGH INTENSITY LIGHT SOURCE

(57) By "straight high intensity" we mean the high in-

tensity arc with which a glass condenser is used to collect and converge the light. (58) It is by far the most powerful light source used in motion picture projection, running as high as 800 candle power per square millimeter area of light source area. (59) When properly handled the 13.6 mm trim working at 125 amperes should drop very little below 750 candle power per sq. mm. of light source area.

(60) The light source is very sensitive to faults. Light production falls off rapidly with faulty adjustment or handling. (61) Under proper conditions using a 13.6 mm carbon trim, the arc will produce a total illumination of approximately 19,000 candle power at 70 amperes. At 100 amperes this is increased to about 40,000 c. p. and at 120 amperes to about 63,000 c. p. These figures represent the total light production. They are quoted merely to convey some idea of the effect of amperage, the rise in brilliancy being fairly steady from 70 to 120 amperes.

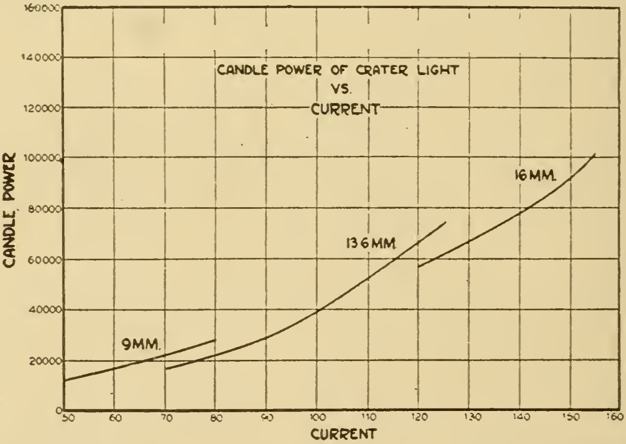

FIG. 148.—Graph shows the candle power of light production compared with the flow of current.

(62) Fig. 149 illustrates a correct high intensity arc adjustment. (63) It is unsafe to be guided wholly by arc voltage in handling the high intensity arc. (64) The light itself is presumed to emanate from the chemicalized

incandescent gases contained in the crater. The action is not yet fully understood, (65) but the light brilliancy is far greater than the brilliancy obtainable by carbon incandescence at volatilization temperature.

(66) The crater must be kept filled with this gas at all times. If the gas were not confined in the crater it would flow out freely and the high intensity effect would be almost wholly lost.

(67) The confining agency is none other than the stream of electrons emanating from the negative carbon, ordinarily termed the negative gas stream or "flame." It performs its work well only when the negative carbon tip is located at exactly the right point, as illustrated in Figs. 149 and 150.

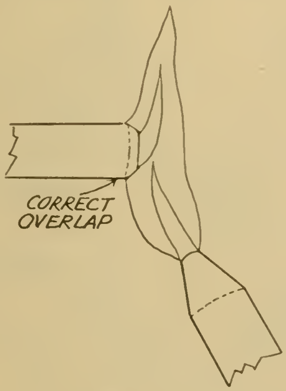

FIGURE 149

(68) The "right point" has been found to be that which will cause the negative gas stream to impinge just a little upon the lower edge of the positive crater.

(69) Fig. 150 shows the exact correct arc gap measurements for a 16 mm positive trim and illustrates the negative position that will avoid loss of light and flickering of the arc.

THE STRAIGHT HIGH INTENSITY LAMP

To explain the text that follows we are showing excellent drawings of a popular high intensity lamp. Fig. 151 shows all the important parts. (70) While it is true that lamps vary more or less in constructional details they all perform the same functions and these drawings are a common guide to all lamps, including your own, no matter what its make is.

Positive Carbon Contacts

(71) The positive contact parts, AA in Fig. 151, are made exceptionally heavy in all high intensity lamps. They are made of the best heat resisting material known.

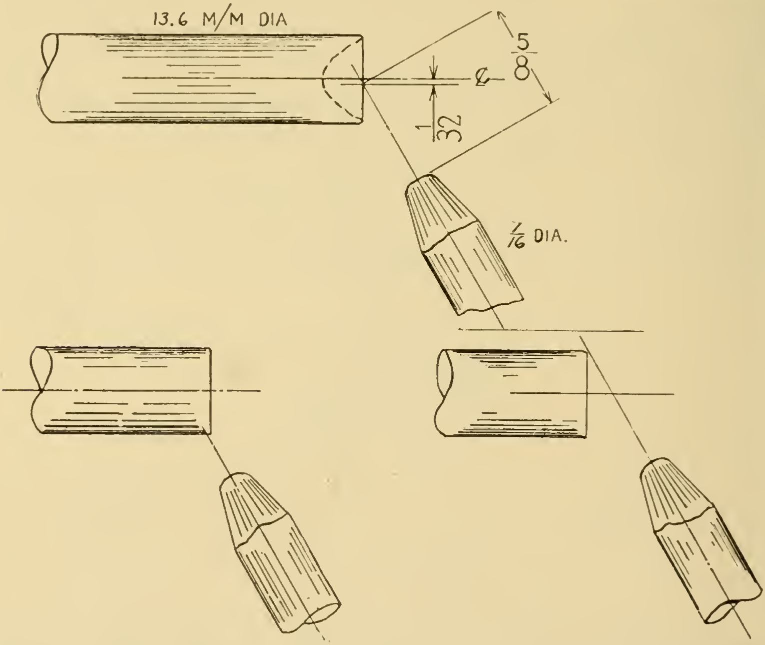

Fig. 150.—Upper illustration shows the correct carbon position. Lower left shows incorrect carbon position resulting in loss of light. Lower right shows incorrect carbon position resulting in a flickering of the arc.

With proper care they will last from 300 to 400 hours. If, through carelessness or otherwise, these contact parts are badly burned and pitted (72) they should be discarded and a new pair put in. (73) To try to file them is futile.

(74) If the contact parts are neither burned nor pitted, they may be cleaned. Remove the contact. Wrap a strip of crocus cloth, or lacking that a strip of No. 1 emery

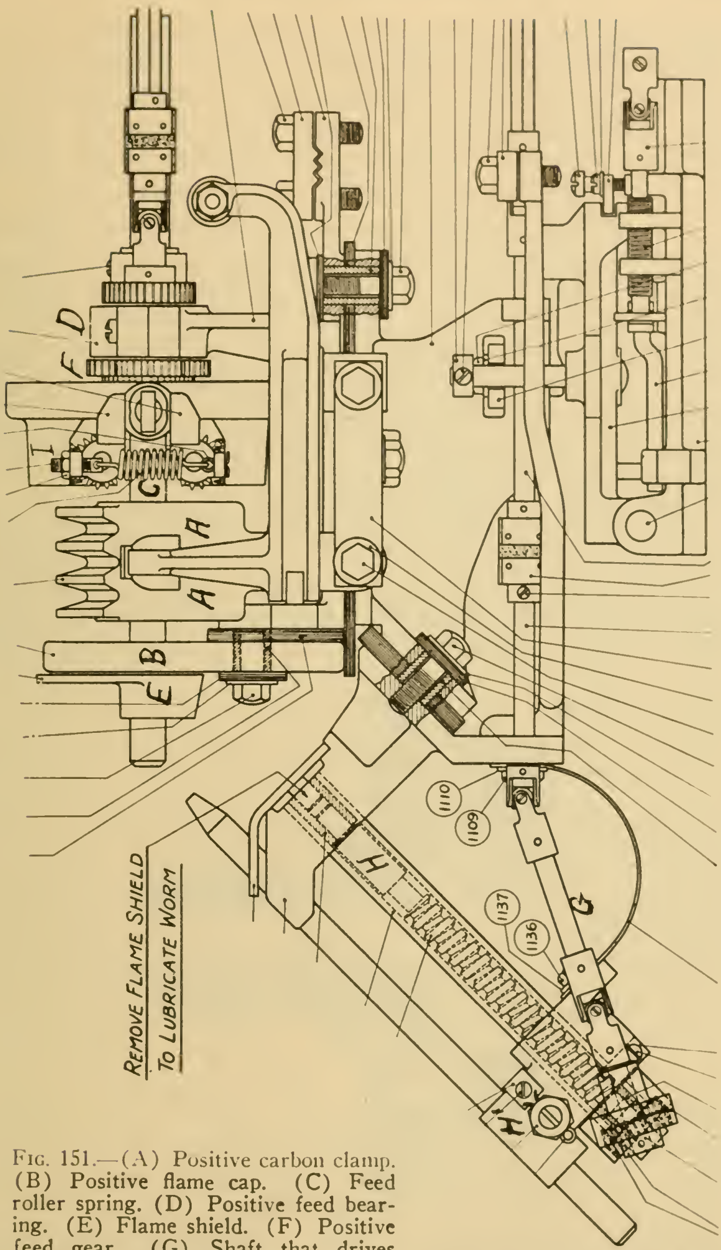

FIG. 151.—(A) Positive carbon clamp. (B) Positive flame cap. (C) Feed roller spring. (D) Positive feed bearing. (E) Flame shield. (F) Positive feed gear. (G) Shaft that drives negative carbon feeding mechanism. (H) Negative feed worm that pulls negative carbon clamp H¹ upward as carbon is burned away. (I) Nut for adjusting positive feed roller pressure.

cloth around a round steel bar 7/16-in. in diameter. (75) If no such bar is available, use a 7/16-in. diameter negative carbon instead. Rub the contact surface until it is clean and bright. Be sure the surface is smooth. (76) Should any minor swelling of the metal be found it may be very carefully smoothed off with an emery wheel.

It is difficult to keep the carbon contacts of high intensity lamps in good condition yet this is one of the most important items. (77) Under the action of high temperature a coating of oxide forms on the contact surfaces, offering high resistance to the passage of current. This resistance increasingly aggravates the condition, the heat generated by the resistance becoming so great between carbon and contact, that the contact metal fuses no matter how "heat resisting" it may be.

(78) This condition demands that the contacts be thoroughly cleaned at least once each day in the manner before described. Some recommend cleaning them only on alternate days, where high current values are not used, but we most emphatically do not regard that as either good practice or safe. It is no hardship to clean them daily and it provides an added element of safety.

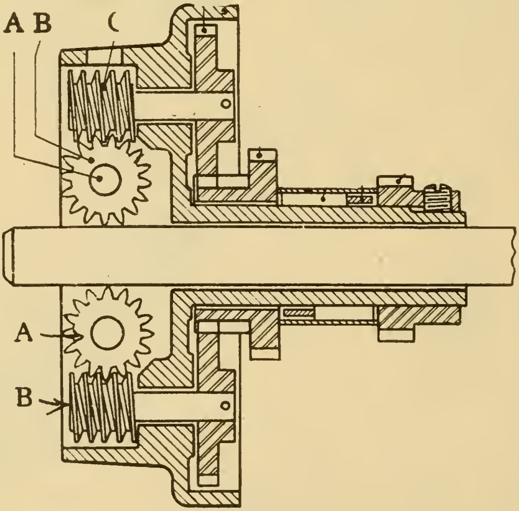

Fig. 152.—Positive feed unit.

(79) It is wise to have spare positive carbon contacts in stock. Not only is it insurance against trouble, but also it enables the projectionist to install a clean set immediately before the day's run, cleaning the old ones at his leisure for use next day.

Positive Carbon Rotation and Feed Unit

(80) This part, shown in full detail in Fig. 152, serves to rotate and to feed the positive carbon forward as fast as it is consumed. The entire part rotates, carying the carbon with it, while at the same time toothed wheels A-A, driven by worm gears C-C, feed the carbon forward as it is burned away at the arc. Wheels A-A are held against the carbon by the pressure exerted by spring C as shown in Fig. 151. The tension of spring C may be altered at will by means of nut I, shown in the same illustration.

(81) The entire unit illustrated in Fig. 152 operates in high temperature and so its working parts must be kept well lubricated. We have always recommended a mixture of powdered graphite and kerosene but some lamp manufacturers object, claiming that the graphite binds the parts. That may be true of graphite grease but a well powdered, pure graphite will not bind up the parts and is one of the best high temperature lubricants known to science. A high grade automobile oil is also good. Whatever you use it is important to keep the parts well lubricated. Graphite, if used, must be in powdered form, mixed with kerosene. The kerosene will burn away at once leaving the part lubricated with dry graphite.

When Positive Carbon Fails to Feed

(82) The trouble usually may be traced to rough, pitted current-carrying contacts. Sometimes—but seldom—it is due to faults in the feeding mechanism. The parts must contact the carbon with sufficient pressure to insure its movement. The feeding toothed rollers are held against the carbon by coil spring C as in Fig. 151, the tension being adjustable by nut I.

(83) The tension should be enough to insure certainty of feeding when the current-carrying contacts are smooth and in good condition.

(84) Too much tension wears the parts unnecessarily. It may even cause roughening of the carbon's outer surface, which would weaken the current-carrying contact. Excessive tension may cause "sticking" when bits of carbon, adhering to the outer surface, are forced into the contact. On the other hand too little tension makes for unevenness, or may even stop the feeding completely.

(85) In case the positive carbon ceases to rotate and feed forward, ease up on the contact pressure and try to finish the run. Then carefully examine the contacts for roughness. If they are rough remedy that at the earliest moment or the contact blocks will be ruined quickly.

(86) To make a quick test for roughness, place the lamp in re-trim position, release the feed mechanism and shove the positive carbon backward and forward several times through the current-carrying contact. With the front end of the carbon extending out in normal operating position, and with the feeding mechanism released, you should be able to move the carbon backward and forward easily. If it binds more than it should, then one of two things or both, is the trouble. Either the pressure of the contact blocks is too heavy or the contact surface is roughened. Smooth the contacts and (or) adjust the contact pressure.

HIGH INTENSITY CARBON CONTACT PRESSURE

(87) Too little contact pressure causes arcing and quickly-roughened, burned contact surfaces. Too much pressure places undue strain on the feeding mechanism and may cause the carbon to stick—to fail to rotate and feed. (88) There must be good electrical contact between the rotating carbon and its contacts or trouble will result.

(89) Always have spare feeding mechanism parts in stock, ready for use. Ordinarily the controlling spring and parts that contact the carbon are sufficient to have on hand for an emergency.

The Flame Shield

(90) All high intensity lamps have a flame or heat shield plate mounted between the arc and the positive current-carrying contact as a protection against the terrific heat of the arc. In some lamps the hole in this plate through which the carbon passes is bushed with a separate metal part. (91) Neither the hole in the plate or the bushing must be allowed to fill up with carbon dust or oxide, until it reaches the carbon. (92) Carefully examine the hole before starting the first show each day. Whenever necessary remove the plate or bushing and clean out the hole. (93) Never attempt to operate a high intensity lamp without a flame shield. If a bushing is provided do not run without it in place. It is possible to do so, but the positive carbon will taper back too much and the contact blocks will soon be injured. Keep spare bushings on hand if your flame shields are equipped with them.

The Negative Head

(94) The negative head carries the negative carbon and its feeding mechanism. (95) It must be adjusted so that when the negative carbon tip is raised into contact with the positive it will be exactly central in lateral relation to the positive. It must be able to maintain this position until the negative carbon is consumed.

(96) In all lamps the negative carbon is clamped and has its main current-carrying contact several inches below its upper end, but just above this is a sliding loose contact through which the negative carbon receives a portion of its current. (97) The projectionist should see to it that the carbon bears firmly upon the metal of this groove, and that it lies central therein. This last is quite important. (98) If it does not, make whatever adjustment is necessary to line up the carbon properly. The method of adjustment differs with different makes of lamp.

(99) The main points to watch with relation to the negative head are to keep carbon in exact alignment, to

keep moving parts (feeding mechanism) well lubricated, and to keep carbon contact clean and tight.

(100) The selection of proper carbon trims, burning them at the most efficient amperage for the trim and maintaining exactly correct position of the negative and positive carbon tips with relation to each other are all vital points, particularly with high intensity arcs.

(101) The high intensity carbon is very critical with regard to current flow; burning below the rated capacity results in heavy loss in light production and is injurious to light quality. Burning above rated capacity wastes both current and carbons.

SPEED OF CARBON CONSUMPTION

(102) The following approximate speeds of high intensity carbon consumption will enable projectionists within reasonable limits to estimate whether or not a positive carbon stub is long enough to run an additional reel, if the footage of the film on the reel is known. Rated amperage is assumed in each case.

9 mm positive, 4 minutes per inch—15 inches per hour.
13.6 mm positive, 4 minutes per inch—15 inches per hour.

(103) Often stubs of carbon are discarded which might serve for another reel, or at least a short reel, if the projectionist knows just how much time is required to consume each inch of carbon. The above figure may be accepted as correct for rated amperage. If the amperage is changed, the time, of course, will be altered. For example, while a 9 mm carbon will only burn 12.8 inches per hour at 75 amperes, it will consume 22.4 inches per hour at 85 amperes.

(104) We recommend that projectionists record the exact burning time of the positive and negative carbons for one full day. To do so, note the exact time the arc is struck and cut off at each run. When you have finished with the carbons divide the exact number of inches of carbon consumed by the number of minutes of running time—this will tell you what fraction of an inch of carbon is used per minute. Record this information for

future use. Remember, if you change either the amperage or the carbon diameter you will alter the amount of carbon burned per minute but it is no big job to compile data covering all amperages used in a given theatre.

(105) The experienced projectionist can estimate current flow fairly well by observing the light source and rheostat settings. But for accuracy use a reliable, properly calibrated ammeter placed where the projectionist may observe it easily. "Guessing" by rheostat setting, or the appearance of light source is often misleading.

Ventilation for High Intensity Lamps

(106) Heat in the lamphouse is injurious to its wires, insulation and other materials and is very trying to the projectionist. On the other hand too much ventilation makes the light source unstable. (107) It is a safe rule to have all the ventilation possible without disturbing the light source. The projector shutters now used direct a strong blast of air toward the lamphouse and it is well to protect the forward vent holes with a metal shield having an opening at the sides.

(108) Always have the dowser closed when you strike a high intensity arc, but do not keep the dowser down too long while arc is burning unless you want a damaged dowser blade. If the dowser is not down while you strike arc you may get a badly pitted collector lens. The high intensity arc throws off minute particles of incandescent carbon at the instant of striking the arc.

(109) After each reel is run, examine the collector lens or mirror and brush off any ash or dust that may adhere to its surface.

Reflector Type High Intensity Light Source

(110) All these rules relating to the straight H. I. light source applies equally to the reflector type H. I. light source. The equipment involved is different in many ways, but the light source is exactly the same, only its

amperage limit being lower, (111) its range being from 60 to 85 amperes. In some makes of lamp the negative is carried at essentially the same angle as in straight high intensity light sources. In others the angle is much less.

Low Intensity Reflector Type Light Source

(112) When properly handled this type supplies a substantial amount of yellowish-white light per watt of power. (113) First, the light source area is small and therefore well adapted to an aperture of limited dimensions. Second, as compared with types from which light is collected by a thick heavily-curved double-lens condenser, the loss through reflection and absorption is almost negligible. Third, the mirror collects a very large angle of light—that is, a very large percentage of the total light.

(114) The total light production varies with varying amperage, carbon trim, etc., (115) but averages about 165 candle power per square mm of crater floor area. This figure applies to the low intensity arc only. (116) With carbon trims in right relation to the amperage, current flow may vary from a low of 12 amperes to a high of 50 though motion picture projection seldom requires more than 30 amperes.

(117) The average increase of crater area per ampere of added current is about 1.85 sq. mm. This varies somewhat, but is sufficiently accurate to be used in roughly computing the light production power of different amperages. (118) The core brilliancy is fairly uniform, but somewhat lower than that of the crater floor formed upon the carbon immediately surrounding it.

The lamp itself is mechanically simple and easy to handle (119) requiring but a few things to observe in its operation.

Use the proper carbon trim, including carbons of right kind and of correct diameters, operated neither above nor below their rated amperage capacity.

Place the positive carbon in correct alignment with the optical axis of the projector optical train and in exactly central position.

Place the negative carbon in exact alignment with positive, but so located vertically that the crater burns as flat as possible and squarely facing the collector.

Have firm, clean, smooth contact between carbons and carbon contacts throughout entire length of the contact.

The arc control should maintain the arc gap steadily with as little variation in length as is possible. Many projectionists have fluctuating light production either because the arc control is in poor condition or improperly adjusted or because the arc control is badly designed and will function only when unnecessary variation in the arc gap occurs. It is entirely possible to so design an arc control that less than ½-volt variation in arc voltage will cause it to function and feed the carbons forward. Controllers that will not do this should be refused.

Keep all electrical contacts clean and tight. Take loose lugs from the lamp binding posts and clean the contact surfaces with crocus cloth or 00 sandpaper (preferably the cloth) once each week in all-day theatres and once in two weeks in two-a-day theatres. Even if the metal looks clean take the precaution to polish the surfaces with the crocus cloth or lightly with the 00 sandpaper. A thin, almost invisible scale of oxide coating having high resistance power frequently forms, especially if the contact is not set up very tight.

(120) Examine all wires inside the lamphouse frequently. If they feel stiff and springy they are all right. If they do not, slit the insulation, pry the strands apart and examine them. If the interior of the wires is brown instead of copper colored, they are already offering too much resistance to the current flow and should be replaced immediately. Wires that are brown on the outside but still do not bend easily and are copper colored inside (asbestos-covered stranded wire) are still fit for use but should be examined frequently.

See to it that the backing of the collector-converging mirror is in good condition and that its face is perfectly clean and nowhere pitted. (121) It is an excellent plan to wash the mirror each morning while it is still cold. Use strong soap suds, rinse it off thoroughly and then polish.

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Be careful not to get the back of the mirror wet, as water damages some types of mirror backing.

(122) Mirrors may be cleaned with a fifty-fifty solution of water and pure grain alcohol. Never use wood alcohol or denatured alcohol because it will leave a thin coating on the glass.

Positioning the Mirror

(123) The light source must be at precisely the right distance from the mirror, and the mirror must be exactly the right distance from the film plane at the projector aperture—not from the cooling plate, but from the film itself.

Even so small an error as the fraction of a millimeter in the distance of the light source from the mirror may reduce the screen illumination, though a small error in the distance of the mirror from the film plane will do no serious harm. It is best to have all measurements exactly right. The lamp manufacturer will supply the exactly correct distances.

To obtain the right distance follow these simple instructions: First, before inserting the carbons, cut a stiff wire exactly the length of the distance the lamp manufacturer recommends between mirror and film plane. Stretch this wire through the carbon clamp openings and with it locate the mirror at exactly the right distance—which will be the length of the wire from the film plane to the surface of the mirror beside the hole in its center, or to the center of the mirror if there is no hole.

Next, cut small copper wires, say about a No. 10, as long as the distance that is recommended between the light source and mirror. Install two carbons and burn them until a normal crater floor has been established. Then, after the parts have cooled down, locate the crater where the mirror surface, about 2½" from its center, just contacts the end of the wire all the way around when the other wire end is in contact with the crater center.

By this method the mirror will be very close to correct position, though not exactly. For one thing, the center of the crater floor being the carbon core, it is likely to be depressed below the rest of the crater floor; also the wire end may not be precisely at the crater center.

Next, having set the projector rotating shutter at open position and blocked up the automatic fire shutter, project the white light to the screen (the projector not running), and move the mirror very slightly toward and away from the light source; watch the results upon the screen closely. Make all possible experimental mirror adjustments very slowly and cautiously, until the point is found where there is both maximum illumination and evenness of light distribution upon the screen. When you get that lock the mirror into place. The position of the mirror should be checked at reasonable intervals to make sure that it has not been disturbed.

(124) In the matter of lubrication the projectionist should follow the recommendation of his lamp manufacturer. Not all of them use the same materials for bearings of moving parts. Some demand that no lubrication be applied to any part of their lamp. Other manufacturers suggest lubricating certain parts only, but not all agree on what lubricant is best.

For lubrication of parts working in high temperature we firmly believe that a mixture of pure powdered graphite and kerosene is best. Some lamp manufacturers condemn its use, claiming it clogs up the bearings, but this, we believe, is due wholly to the use of impure graphite or graphite mixed with grease. Graphite-grease mixtures must not be used at all. We suggest that the lamp manufacturer's recommendation be followed implicitly and in the event trouble arises from the use of an improper lubricant, the manufacturer will have to bear all responsibility.

OLD STYLE D.C. ARC

(125) Since this type of light source is now seldom used for theatre projection (because of its poor efficiency it should not be used at all), it is neither necessary nor

desirable to deal with it extensively. In these lamps cored carbons of proper diameter should be used, neither over nor under loaded, with the negative tip adjusted so that the crater of the upper carbon will face the collector lens.

Low Amperage Non-Rotating Carbon H. I. Arc

(126) Until recently the great majority of projection arc light sources have been of two types, namely, (a) the high intensity, both straight and reflector type, and (b) the low intensity arc, a type of lamp in which the carbons operate at low current density. (127) By current density is meant the amount of current flowing per square inch of carbon area.

The high intensity arc carbons considered heretofore all have a relatively large diameter (9 to 13.6 mm positive) with a shell of pure carbon and a core of carbon intermixed with a binder and elements known as the "rare earth groups." These carbons are operated at from 65 to 130 amperes, according to their size, giving a high current density and providing a very brilliant blueish white light.

The low intensity arc used a carbon from 10 to 14 mm in diameter and was operated at from 15 to 40 amperes. This meant low current density as compared with the high intensity arc carbons, and did not produce so brilliant a light per square mm of light source area. The light lacked the blue-white radiance provided by the high intensity arc.

(128) The new, non-rotating positive d.c. high intensity arc uses a very much lower amperage than does either the straight or reflecting type high intensity light source, but its carbons, nevertheless, have high current density and its light is quite brilliant.

This is due to the relatively small diameter of the carbons (6 to 8 mm), operating at from 35 to 65 amperes. Moreover a greater percentage of the total light is available to the projection lens by reason of the fact that the light source area is smaller, and that is a very important point when we are considering a light source from which the beam must be passed through an aperture of restricted size.

(129) Several elements must be considered in determining screen illumination, namely, the brilliancy per unit area of the light source; the total area of the light source; the percentage of the total light collected and passed on to the spot; the percentage of light at the spot that falls upon the aperture opening; the percentage of light beam on projection lens side of the aperture that enters the lens and the percentage of light that is cut off by the rotating shutter.

In this discussion we are interested only in the fact that in the new arc the crater (light source) has a small diameter and therefore a much greater percentage of its total light will pass through the projection lens. This will be better understood by studying the optical section of this book. The data concerning Suprex carbons will be found listed on page 371.

(130) As already said, the high intensity arc produces higher unit area of brilliancy. It is the only method known by which any considerable increase in d.c. screen illumination over that supplied by the low intensity arc may be obtained, save only the high amperage old-style straight arc which did deliver brilliant screen illumination but consumed very much more power.

(131) In the past the 9 mm diameter high intensity carbon was the smallest made and it required at least 70 amperes of current to produce satisfactory results. The chief difference between the light source we are now discussing and other light sources is that it is a high intensity arc using small diameter carbons and operating at low amperage, but (132) at current density approximately equal to that of the larger diameter high intensity carbons.

While it is quite true that the light from these new small diameter high intensity carbons per unit area approaches that of the larger high intensity carbons in brilliancy, still the total output is considerably less because the carbon has a smaller diameter and therefore a reduced light source area. As before related, however, a greater percentage of it will reach the projection lens. Other relatively unimportant items tend to aid in rendering this light source very efficient.

(133) For example, the carbons being copper coated, much of the current passes from the contact to a point close to the crater through the copper instead of through the body of the carbon, thus avoiding heating the carbon by resistance. This has two other advantages. Since the positive is non-rotating, the contact clamp may be placed back a considerable distance from the crater. It may be a plain clamp, thus eliminating the machinery for operating a sliding contact and rotating the carbon, giving the mechanism great simplicity. Again, were all the current to pass through the body of the carbon, it would heat progressively toward the crater, developing a tendency to spindle-burn to a long, tapering point.

(134) As was noted before the crater of the high intensity arc light source must be cup-shaped and deep and of even height at all points so that the luminous gases generated therein by volatilization will be retained. The gases are held in the crater by the impact of the negative gas stream.

This stream or flame must be at a slight angle to the face of the positive crater so that all surplus gas is compelled to leave the crater in an upward direction. When the negative is wrongly positioned the surplus gas escapes at various points on the rim of the crater, resulting in an unstable arc and poor screen illumination.

The proper condition is established in the regular high intensity arc by placing the negative carbon at an angle to the positive. (135) In the non-rotating carbon high intensity arc both carbons are centered on the axis of the optical system, hence lie approximately in horizontal position, but in order that the negative gas stream may strike the positive crater at the desired angle, the negative is located with its center a trifle lower than the center of the positive carbon. The action of the gas stream is then aided by forcing it upward by means of a magnet, the current of the arc being influenced by magnetic force.

CARBONS IN LINE

(136) While the negative must be a trifle below the positive, both must otherwise be in exact alignment with each other. If they are not the crater lip will burn unevenly giving poor illumination.

(137) Extreme drafts of air, particularly those caused by projector rear shutters, passing through the lamphouse disturb this type of arc. Where rear shutter blades have vanes to force the draft, the front vent holes of the lamphouse must be either well protected or closed. Some lamp manufacturers recommend the removal of the vanes, but that is merely robbing Peter to pay Paul since it increases the heat at the projector aperture.

(138) It is quite possible to protect the front lamphouse vent holes from such air currents as the rear shutter sets up. Construct a trough of sheet metal, preferably russia iron to cover the lower holes, the trough having opening at the sides, with a protecting flap bent backwards at the ends, and another at the top, opening upward and back. It is a very simple device and requires only a tinner's shears and an hour of time.

(139) The Suprex carbons used in this light source are made in three diameters, each having a definite current range. Do not attempt to either over-load or under-load them. The 6 mm positive and 5 mm negative combination operates at from 34 to 40 amperes within an arc voltage of 29 to 31; the 7 mm and 6 mm unit operates at from 42 to 50 amperes with an arc voltage of 30 to 34; the 8 mm and 6.5 mm unit operates at from 55 to 65 amperes with an arc voltage of 36 to 40.

(140) In the opinion of competent authorities this light source, when efficiently handled, will produce a very much higher screen illumination per watt of applied power than the low intensity lamp. While it is still impractical to secure more illumination at the screen center with the 8 mm trim than with the 7 mm trim, there is this important difference: the 8 mm trim will supply higher illumination at the edges of the screen image than the trim of smaller diameter, and thus often gives the effect

of even illumination over the entire screen area. The total light production is far below that of the rotating carbon high intensity light source but in conjunction with a specially devised optical system it is highly efficient.

(141) In addition to maintaining a straight, even crater lip and avoiding air drafts, there is another important element—the distance of the arc crater to the vertex of the reflecting mirror. There are three predominant light tones in all high intensity light sources. The carbon shell, being pure carbon, emits light that has a tinge of amber or yellow. Directly in front of the crater floor is a brilliant, pure white gas ball, and in front of this, toward the negative carbon tip, is bluish illumination less intense than that of the gas ball.

The beam of light sent forward to the projector aperture contains all these colors, but (142) they are separated, following each other in the order named. Which of them will be focused at the aperture, and therefore at the back conjugate foci point of the projection lens, depends upon the adjustment of the light source with relation to the reflector. To focus the white light—the best light—at the film plane demands that the positive crater be placed at just the proper distance from the reflecting mirror.

(143) To bring this about the feed mechanism of the lamp must function very accurately. After striking the arc and permitting it to settle down, the projectionist always should adjust it carefully and correctly. Indifferent adjustment will cause a change in the color or tone of the screen illumination.

"One-kilowatt" High Intensity Lamps

(144) The principle of the low-current high intensity lamp has been extended, for the benefit of very small theatres, to the construction of arc lamps utilizing a minimum of only one kilowatt of power. They operate at approximately 27.5 volts and 40 amperes. Their special secret is the low voltage, which in turn has been made possible by development of a special carbon which will

not develop a "mushroom" or "carbide" tip (see Fig. 147, Page 369) when a very short arc gap is used.

SEPARATE POSITIVE AND NEGATIVE FEED

(145) In many of the non-rotating positive, low amperage, high intensity lamps discussed on the pages immediately preceding, a single mechanism commonly controls the feeding of both positive and negative carbons. With such lamps it is very necessary to use the trim (size of carbons) and the current recommended by the manufacturer in all such lamps, or either the positive or the negative will fail to feed correctly. However, a number of lamps of this type are built with separate mechanisms for feeding each carbon, permitting greater flexibility in the choice of carbons and current.

CARBON FEED MECHANISMS

(146) Whatever mechanical contrivances are used to feed the carbons, a small electric motor is always the source of the mechanical power that drives the feed mechanisms. This motor may be mounted within the lamphouse, as shown in Fig. 153 at "F," or it may be located behind and outside the lamp, or under the lamp, or in any other suitable location. The rate of feeding is generally controlled on the start and stop principle. Thus, there may be a relay—an electromagnet—which, when the gap grows too wide because the tips of the carbons have burnt away, allows a contact to close, energizing the motor and feeding the carbons until the arc current has increased to the point where the relay again becomes operative, pulling open the circuit to the feed motor. (The chattering of this relay, if its contact points are not kept clean, sometimes introduces a clicking noise into the sound.) Or there may be a separate coil or winding in the feed motor which acts to speed the motor up when the arc current declines because the gap is widening, and to slow the motor down when the arc current increases again. Either part or all of the arc current may be detoured through the coils of the relay,

or through the special control coil of the type of motor just referred to.

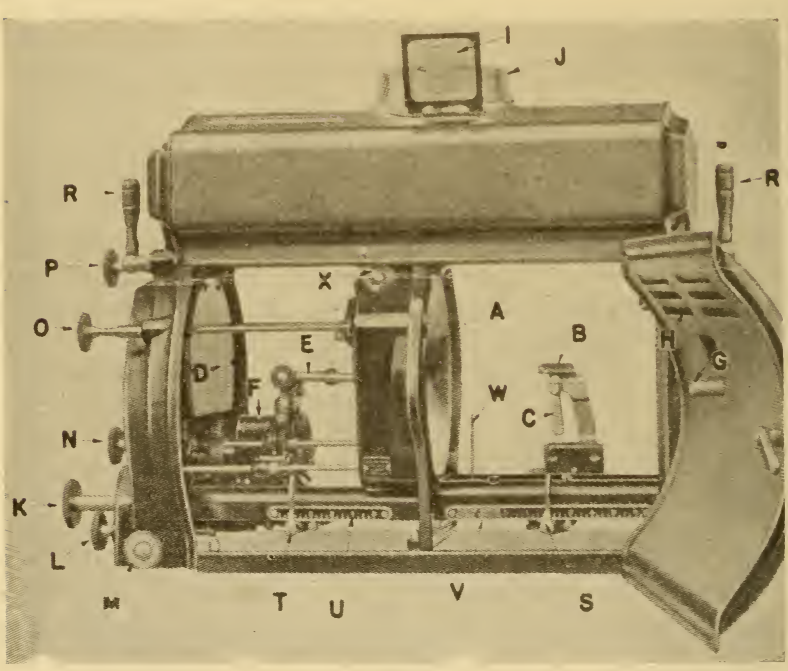


FIG. 153.—(A) Mirror Reflector. (B) Positive Carbon Jaw. (C) Positive carbon clamp. (D) Separate Negative carbon feed adjustment. (E) Negative carbon jaw. (F) Feed motor. (G) Arcoscope lens. (H) Door ventilators. (I) Arcoscope screen upon which image of arc is projected by lens G. (J) Vent pipe opening. (K) Positive carbon hand feed knob. (L) Arc focusing knob. (M) Arc striking knob. (N) Negative vertical adjustment. (O) Mirror horizontal adjustment. (P) Mirror vertical adjustment. (R) Dowser and flame shield handle. (S) Positive carriage quick return handle. (T) Negative carriage quick return handle. (U) Negative carbon feed scale. (V) Positive carbon feed scale. (W) Arc centering indicator. (X) Arc stabilizing magnet.

(147) Fig. 153 shows a Brenkert H non-rotating positive carbon lamp. The carbon clamps are much like those of the low intensity lamps. The negative carbon is movable, up, down, or sidewise, to permit adjustment of alignment. A small magnet sits just above the negative carbon clamp. It has just enough strength to influence the negative gas stream or flame to operate at maximum efficiency. The mirror is eliptical and de-

signed to project a beam that will just fill a projection lens of 2.2 speed. There is a negative feed separate from the positive carbon feed.

96-CYCLE A.C. LAMP

(148) One of the modern one-kilowatt high intensity lamps utilizes a.c. at 96 cycles, derived from a special motor generator. The reason for using this particular frequency lies in the nature of the shutter action. As explained in connection with projectors, 24 frames are projected per second, but the shutter has two blades, so that light is projected twice through each frame, or, in other words, light is projected to the screen 48 times per second and the screen is darkened 48 times per second. Considering each interval of light and of darkness as one alternation, the screen may be considered to be illuminated at 48 cycles—one-half the current frequency.

(149) An a.c. arc is not broken when the current passes through zero amperage (as it does twice during each cycle) because the air and the arc gases retain their ionization long enough to restore the arc instantly when current begins flowing in the opposite direction; and the crater of the carbon and the super-heated gases continue to glow during the moment the current is changing direction; none the less there is a fluctuation in light intensity corresponding to the frequency of the current.

(150) When 96-cycle a.c. is supplied to the carbons, the screen receives the identical amount of illumination each time the shutter opens. The light projected on the screen cannot flicker if the shutter action and the a.c. action are out of step. The shutter remains open approximately 1/96th second. In that time, one complete cycle of current passes through the arc.

(151) There is no need to arrange any synchronism between shutter action and arc current. It does not matter at what point in the current cycle the shutter opens. Whenever it opens, the current will go through one complete cycle before the shutter again cuts off light from the screen. The next time the shutter opens the current will once more complete a single cycle before the

shutter closes. Thus, at each shutter opening, the screen receives the same amount of illumination it did at the last shutter opening. This would not be the case if ordinary line frequency were used.

(152) This 96-cycle a.c. arc, as said, utilizes low wattage high intensity 7 mm x 14″ copper-coated carbons, and operates at 52-66 amperes, 18-22 volts. For trimming, preparing and striking the arc that is not in use at the moment, ordinary line frequency is used. At changeover, the dowser in one lamp is closed while the dowser in the other is opened; simultaneously a control device incorporating relays (electro-magnetic switches) substitutes 96-cycle current for line frequency in the lamp that is about to be used, and substitutes line frequency for the 96-cycle supply in the lamp that has finished projecting its reel to the screen. This is automatically arranged by electrical connections between the control unit and whatever changeover device is installed in the projection room. Fig. 154 shows the driving motor mounted above the rotary converter—this vertical arrangement is used to conserve floor space. In an inset at the top right of the picture is the control unit. This unit, in addition to providing automatic switching, transforms the voltage of the power line and of the converter output to the 18-22 volts required at the arcs.

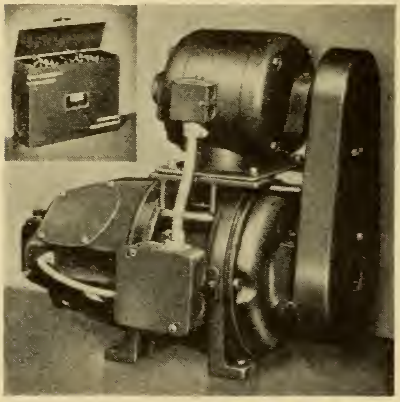


Figure 154

Operation and Maintenance

(153) Arc lamps should be operated according to instructions furnished by the manufacturer of the lamp and by the manufacturer of the carbons. Specifications from those two sources (if up to date) will agree. If

more light is needed use a different carbon trim, or increase the arc current, or adjust the burning rate, but only within limits specified by the makers of the equipment. Conversely, if economy is desired at some sacrifice of screen light, keep any changes made for that purpose within the limits the manufacturers specify.

(154) All lamps are provided with external knobs, dials or other controls by means of which the location of the arc can be adjusted, the arc gap lengthened or shortened, etc. The location of these controls differs in different makes and models. Some manufacturers place them at the back of the lamphouse, some at the right-hand side. The mechanical details of the operation of such controls, and of their association with the feed mechanism, differ in different makes and models of lamps. The projectionist can acquaint himself with all such details by a short study of any make or model of lamp he may be called upon to operate. As there are many different makes, totalling some dozens of models, now in use in the United States, it is impossible to give those details here.

(155) In all lamps, accuracy of the optical alignment and optical focus is extremely important. A misadjustment of only 1/16th inch between arc and mirror may cost an important percentage of the total light generated. The light is useless unless it reaches the screen, and to assure that the maximum illumination will reach the screen optical adjustments must be precisely made. The details of those adjustments, again, differ in different makes and types of lamps, and in this matter also manufacturers' instructions must be consulted.

(156) To understand the importance of this point, the projectionist need only remember that by far the greater part of all the electrical power consumed in the projection room is consumed in the arcs; waste there arising out of improper adjustment will represent a substantial waste in the theatre's bill for projection room electricity. Further and more important, improper arc adjustment will result in a dull screen image, a visible and glaring fault that repels audiences. And it is the

audience, in the last analysis, that pays for the projectionist's services.

(157) Lamp manufacturers issue very detailed instruction books, in which carbon feed and control mechanisms of their products are carefully diagrammed, with every mechanical part numbered to facilitate correct naming of any replacement parts desired. These books accompany every lamp sold; they should be kept in the projection room. If they have been lost or misplaced, duplicates should be requested. Any mechanical detail of a given lamp that is not made thoroughly clear by inspection of the actual mechanism should easily be clarified by reference to the instruction book for the lamp in question.

(158) Manufacturers' instruction books also cover details of operation, adjustment and maintenance—details which differ from lamp to lamp and therefore cannot be covered here for all the many lamps now in common use. In the matter of lubrication, for example, there is a wide variance in manufacturers' specifications. The feed mechanism, consisting of moving parts, normally should be lubricated, but some manufacturers demand that no lubrication be applied to any part of certain of their lamps. Others specify different types of lubricants at different points, which is reasonable enough when it is remembered that a thin oil suited to the carbon feed motor may be entirely inadequate to lubricate a large worm gear. Again, some parts of the feed mechanism are, in some lamps, located entirely outside the lamphouse proper, and therefore run comparatively cool; while other parts of the mechanism in the same lamp are exposed to extreme heat. Manufacturers designate lubricants accordingly, and their designations are the only safe guide to proper lubrication of their products.

(159) Cleanliness of the optical surfaces is essential to prevent loss of light. The mirror and mirror guard, and the condenser, if there is one, should be kept scrupulously clean. Penalty for neglect in this matter will be serious and inexcusable waste of light. Thorough cleaning of the optical elements should be part of the morning

routine that ought to precede each day's operation in every theatre.

(160) Do not use ordinary rags to clean optical surfaces. Cotton will scratch optical glass. The very best material is lens tissue. This is a special paper, quite inexpensive, that will not scratch glass and will not leave lint. It may be moistened with a mixture of alcohol and water, or with carbon tetrachloride. Unless the surface is seriously soiled the dry tissue will probably do a satisfactory job. Soap-and-water, Bon Ami-and-water, etc., can be used, but there is always a chance that soap in particular will not be entirely flushed away; that a thin layer of it will remain as a coating. But water, alcohol and carbon tetrachloride will all evaporate completely.

(161) In the absence of lens tissue, try to obtain silk for cleaning optical surfaces. The soft type of paper handkerchief can be used, but tends to leave lint. A rag of wool, or better still of soft flannel, is acceptable. Avoid cotton.

(162) The floor of the lamphouse should be kept clean of carbon or copper particles. Many projectionists prefer to brush out such rubbish after every reel.

(163) Contact points of the carbon feed control relay (if there is one) should be subjected to routine cleaning with carbon tetrachloride. If serious sparking appears, the relay tension should be adjusted, or the contact points cleaned with fine sandpaper, crocus cloth, or a fine file.

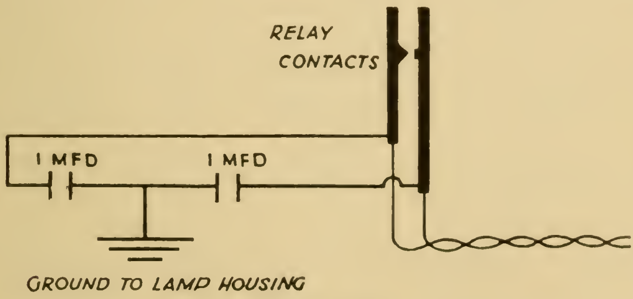


FIGURE 155

If the relay action introduces noise into the sound, and cleaning and adjusting the relay does not cure the condition, obtain two 1 microfarad, 100-volt electrical condensers, wire them in series and then connect them across the relay contacts, grounding the wire that joins the two condensers. If the feed motor commutator introduces noise into the sound, and cleaning the commutator and adjusting the brushes fails to cure the trouble, connect the same type condenser arrangement across the brushes. The connection is diagramed in Fig. 155.

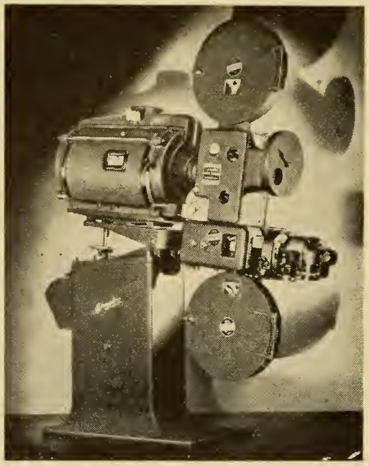


FIGURE 156

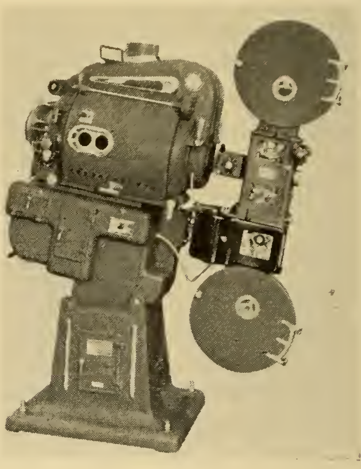


FIGURE 157

FIG. 156.—Complete projector assembly. At left, bottom, pedestal, with removable panel through which enclosed wiring can be reached. At extreme left of pedestal, enclosed switch controlling arc current. Above the pedestal, the lamphouse. An image of the arc is reflected upon the card at the top of the lamphouse, just below the chimney, and should fall between the two vertical lines on the card. The arc can be viewed directly through the dark-glass window in the door. The door hinges upward. The dowser control handle is shown to the right of the dark glass window. At right, from top to bottom, are the upper magazine, projector mechanism, soundhead (with drive motor to the right of the soundhead) and lower magazine.

FIG. 157.—Complete projector assembly. The pedestal is equipped with several hinged doors for access to internal wiring and compartments. The enclosed arc current switch is at the extreme left of the pedestal. Five arc control handles protrude from the side of the lamphouse at the rear, and two more controls are located behind the lamphouse. An image of the arc is focussed on the card just left of the chimney; the arc can also be viewed directly through the two dark-glass, circular windows. The door hinges upward. The row of holes along the bottom of the door is for ventilation. The dowser control lever is to the right of the door. Above it and a bit to the left is the ammeter, which reveals the arc current. At right are, from top to bottom: upper magazine, projector mechanism, soundhead and lower magazine. The drive motor is on the other side.

Filament Lamp Projection

Filament-type lamps continue to be used successfully for motion picture projection in many theatres, and in schools and public auditoriums. (164) They possess such advantages as cleanliness, low cost of operation, minimum fire hazard and are free from hot lamphouses and the gases generated by carbon arcs. They are simple and once adjusted give little trouble. (165) Their effectiveness in screen illumination, when used in conjunction with good optical system may be compared favorably with illuminants consuming considerably higher wattage.

(166) Filament illumination is characterized by a very agreeable softness with none of the harsh brilliance of light that comes from the high intensity electric arc. (167) There is some change in the appearance of color pictures with a filament-type light source. The change is noticeable principally in the blues and reds—the former being somewhat deeper in color and the latter appearing somewhat more brilliant.

(168) Filament lamps used for projection possess characteristics quite different from those used for general lighting. Projectionists should have a good knowledge of their character and limitations and know what optical systems may be used.

General Characteristics

(169) Filament-type lamps produce light as the result of heat generated by the resistance which opposes the flow of an electric current through a high resistance metallic lamp filament. (170) This filament is of tungsten wire, because tungsten has the highest melting point of any known metal. It may be raised to a very high temperature, hence produces the whitest light, as well as the greatest amount of light per watt of applied energy of any material available for such purposes.

The filament is enclosed in a glass bulb which serves to prevent chemical action between the white-hot wire and the oxygen contained in the air. Were the filament in contact with oxygen it would be burned out almost immediately. (171) Lamps employed for projection service are filled with a chemically inert gas, as nitrogen or argon, which serves to retard the burning away or evaporation of the tungsten, thus either prolonging the life of the lamp or enabling the production of more light for a given life.

The average life of a filament-type lamp at any given voltage or current flow can be controlled, within relatively wide limits, by design. (172) The lamps that are built for theatre projection service last an average of 100 hours; in some instances this is dropped down to 50 hours. In effect this means that the current flow has been fixed at a level which allows theatre projection lamps 100 hours of useful life or 50 hours, as the case may be. Lamps for portable projector service are usually designed for an average life of 25 hours.

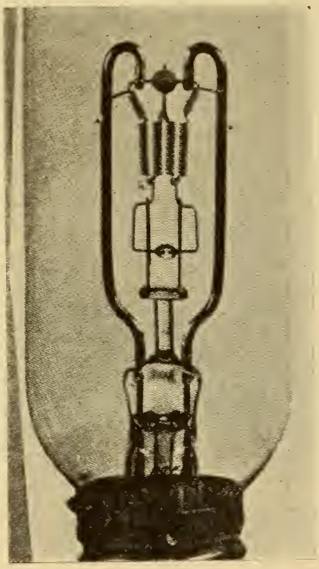


FIGURE 158

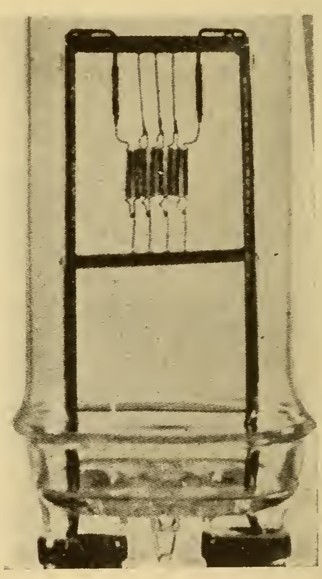


FIGURE 159

(173) There are several outstanding characteristics of projector filament lamps that distinguish them from other, more ordinary, filament lamps. The coils

of filament wire are arranged to secure the highest concentration of light, as in the "monoplane" type illustrated in Fig. 158. By this arrangement most of the light output of the lamp is available to the condensing lens and mirror, and relatively little is wasted at the sides. It produces more screen illumination per watt of electrical power. (174) The additional coils of the "bi-plane" type, shown in Fig. 159, double the current consumption (wattage), so that while biplane lamps consume more power and produce more heat, they make possible gains in screen illumination of 50 to 100 per cent. (175) Within defined limits the length of the filament wire determines the voltage that may be applied to a lamp and the diameter or cross-section of the wire determines its amperage capacity.

(176) Other things being equal it is better to connect the lamp directly to a 115-volt line. However, it has been found that the light source area can be reduced by using shorter filaments of a greater cross-section area. These lamps are of the low voltage type and are used in theatres where voltage reducing devices such as transformers or resistors may be employed. They are designed for low-voltage and heavy current duty and offer a greater light intensity per unit area of the light source than lamps of 115-volt rating of the same wattage and life. With portable projectors, where the bulk and weight of the current controlling equipment is important, "line" voltage lamps are employed.

(177) The share of the total light a condenser collector lens of given diameter will pick up depends largely upon the distance of the light source from the collector and the diameter of the collector. This is exemplified in Fig. 88. In order to reduce this distance as much as possible and thus increase the angle of pick-up, projection lamps are made with bulbs of the smallest permissible diameter.

THE LONG BULB

(178) To secure enough space inside the bulb for the wattage consumed, projection-type lamp bulbs are made somewhat longer than at first glance seems neces-

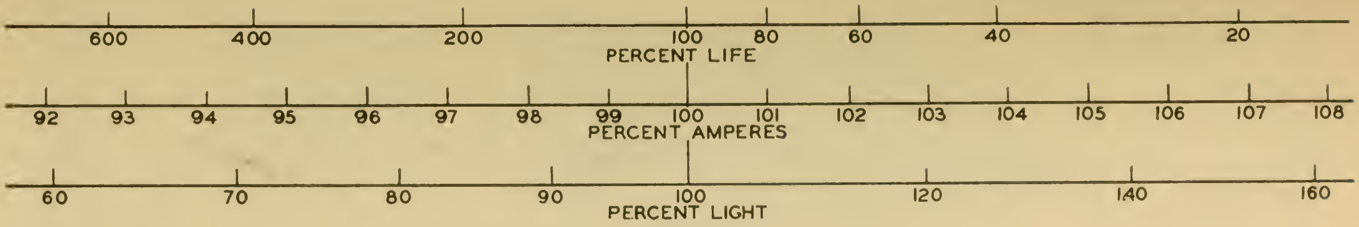
sary. The extra bulb length serves another purpose: The extra space is all above the filament and it is in this upper portion of the bulb that the blackening (tungsten deposit from the filament) takes place, where it does not interfere with the passage of light.

(179) Some projection-type lamps are designed to operate at constant voltage, others at constant amperage. Both types present advantages but a lamp designed for constant voltage operation will not give its best performance when at constant current, nor will a constant current lamp function at its best at constant voltage.

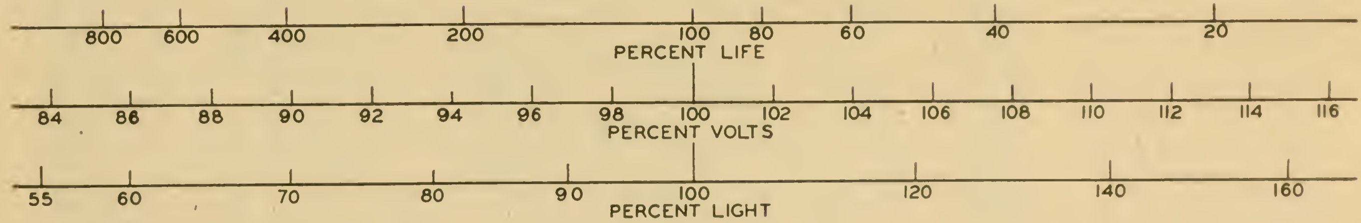
(180) The older types of theatre projection lamps like the 900-watt, 30 ampere unit, were designed to burn at constant amperage. As the filament evaporates the cross-section area is reduced which in turn causes the filament to burn brighter gradually. This increasing brightness is compensation for the blackening of the bulb opposite the filament and more or less maintains constant screen illumination throughout the life of the lamp.

(181) Some of the newer models of projection-type lamps contain a small amount of granulated tungsten powder inside the bulb. When the interior of the globe begins to blacken it is only necessary to remove the lamp from its socket and, holding it on its side, shake the lamp until the powder has scoured off all the deposit. Projectionists using lamps thus equipped should at regular, not too infrequent intervals of time, remove the lamp and scour off any deposit that may be on the sides of the bulb.

(182) The life and light output of projection lamps are very sensitive to variation in rate of voltage or amperage. Fig. 160 illustrates the effect of departing from rated values. Projectionists should be very careful to operate their lamps as close to the values marked on the bulb as is possible. (183) A projection-type lamp is capable of producing a relatively high screen illumination for the wattage consumed, but it must be remembered that both lamp life and screen illumination are greatly affected by changes in voltage or current.



Variation of light and life with change of current.



Variation of light and life with change of voltage.

Fig. 160.—These charts represent the effect of overloading. Center line of upper diagram shows that if the lamp operates at only 92% of its normal rating, its life will be increased about 625% and its light power decreased to a little less than 60%. If the load is 8% above normal the life of the lamp will be a little under 20% but the light power will jump to over 160%. The lower chart may be analyzed the same way.

Here again the accurate alignment of the light source and condenser with the aperture and projection lens is imperative. (184) The figures following show the extent to which screen illumination is reduced when the alignment of the light source is inaccurate. One hundred per cent projection values are to be obtained only when the filament is centered on the optical axis. Here is an indication of what happens when the filament is off center.

Filament out of center up or down
1/16 inch, light 96.0%; 1/8 inch, light 85.3%; 3/16 inch, light 66.6%
Filament out of center sidewise
1/16 inch, light 92.8%; 1/8 inch, light 76.2%; 3/16 inch, light 57.7%

In the above tabulation we see that if all other optical train elements are in correct alignment, but the lamp filament is, for example, 1/8 inch too high or too low, almost 15 per cent of the light is lost; if it is 3/16 inch too far to one side, almost 43 per cent of the light is wasted, which emphasizes the importance of centering the lamp filament exactly on the axis of the optical train.

(185) The majority of the high wattage projection lamps show a certain amount of coil distortion (sagging) towards the end of life. If allowed to continue it may result in a short circuit in the coils. Filament sag cuts down the illumination on the screen or it may cause the lamp to burn out immediately. It is best to replace such lamps to avoid trouble during a performance.

(186) Throwing the full operating load directly on these high wattage, heavy current projection lamp filaments often causes some distortion of the filament. (187) To offset this controls are available that permit the lamps to be burned at reduced current until the filament warms up. In 10 to 15 seconds the various parts of the filament warm up sufficiently so that it is safe to give it the full current load.

PROPERTIES OF THE COMPONENT ELEMENTS

Since the standard professional projector aperture and projection lens present openings of considerable size, a light source of generous area can be used. (188) The maximum size of the light source which can be employed effectively with a given optical system is dependent upon (a) the design of the condenser and its distance from the aperture; (b) the size of the aperture opening, and (c) the diameter of the projection lens.

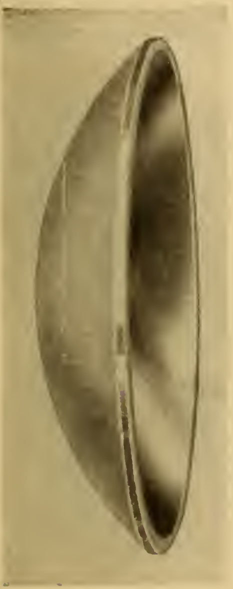


FIGURE 161

Examination of the curve in Fig. 162 shows that in a typical filament-type lamp optical system the screen illumination increases with the increase in the area of light source up to one-half inch square. (189) More than that merely adds illumination to the cooling plate without raising the screen illumination to any appreciable degree. Therefore the light source area cannot be increased beyond the limits of one-half inch square for the 35 mm projector optical system with any beneficial effect. The newer lamps produce additional screen illumination only because, by using the biplane filament form, more filament has been included within the usable one-half inch area.

MIRROR REFLECTOR

Filaments of course emit an equal amount of light in a direction opposite to that of the condenser. It is desirable to make use of as much of this light as is possible. (190) This has been accomplished by locating a spherical glass reflector, pictured in Fig. 161, behind the lamp. This mirror reflects from 80 to 85 percent of the light incident upon its surface and the greater part of the light is brought to a focus in the plane (or planes) of the filament, in the form of an inverted and reversed image of the filament. (191) In the case of the monoplane filament the mirror is positioned so that the image of the filament dovetails with the filament coils. With the mirror adjusted in this way, most of the reflected light flux merges with the beam from the filament coils and passes on to the condenser lens.

(192) Two important advantages result. First, the screen illumination is increased from 50 to 75 percent more than is delivered by non-mirror lamps. Second, the source becomes in effect a solid luminous rectangle which gives a greater uniformity of screen illumination.

Since the biplane filament light source substitutes actual coils of tungsten wire for those formed by the mirror, it might at first appear that the spherical reflector is of little advantage. (193) However, examination of the biplane flament from an angle of forty-five degrees on either side shows several openings through which the mirror can project light to the condenser. Furthermore, the energy directed back to the source raises its temperature without expenditure of current and thus to some extent increases screen brightness. As a matter of fact it has been found that the use of a spherical mirror with a biplane lamp increases the illumination of the screen very considerably.

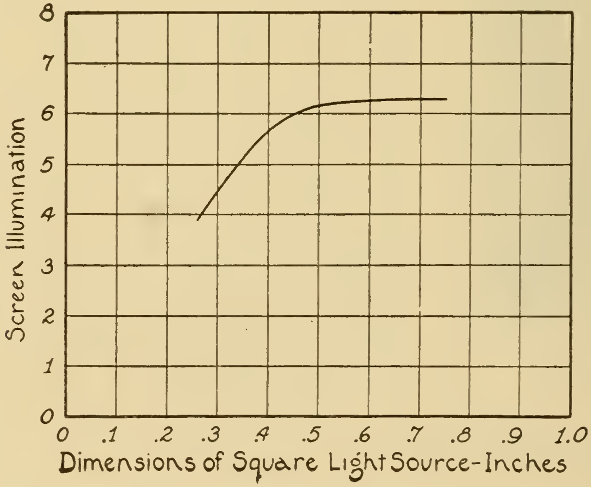


Figure 162

MIRROR ADJUSTMENT

Adjustment of the mirror so that its beam falls exactly in the right position on the biplane filament is not as simple as in the case of the monoplane lamp. (194) The mirror should be moved backward and forward until the image of the source, as seen on a card held in front of the projection lens, is exactly the same size as is the source itself. The image is then moved laterally and (or) vertically until it exactly covers the source. Then, and only then, is it ready to deliver maximum results.

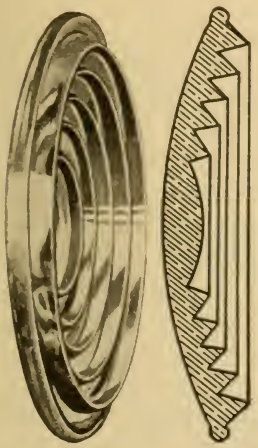


FIGURE 163

Biplane lamp manufacturers intend that a spherical mirror be used in conjunction with their units. They make proper allowance for the higher temperature of the filament caused by superimposing the mirror image upon it. (195) Failure on the part of the projectionist to use a mirror means only that he is satisfied with inadequate illumination of his screen.

CONDENSING LENSES

(196) As related in detail elsewhere, the function of the condenser is two-fold. It collects the greatest possible share of the light emitted by the light source and converges it upon the projector cooling plate and aperture. The part that falls upon the cooling plate represents unavoidable loss provided the spot upon the cooling plate has the smallest diameter consistent with good screen results. If it is larger than necessary there will be a constant, heavy, wasteful loss. See Fig. 165.

Since the light comes from the source in the form of diverging rays, and that portion picked up by the collector lens is a cone having the light source area as its point and the diameter of the collector lens as its base, (197) it is evident that the greater the diameter of the collector lens and (or) the closer the collector is to the light source, the more light will be intercepted, picked up and sent forward to the projector aperture. (See Fig. 88.)

As has already been indicated, the bulbs of filament lamps are made as small as they can be so that the light source (filament) can be placed as close as practicable to the collector lens and in that position, we repeat, the greatest possible amount of the total light emitted will be available to the lens.

Condensing Lenses

(198) The chief value of the aspheric condenser is in considerable measure to correct spherical aberration. As all projectionists understand, the two plain, uncorrected lenses used in the plano convex condenser produce heavy spherical aberration, because each zone (the distance from optical axis) focuses rays at a different distance from the lens than do other zones. The further from the axis they are the nearer the rays are focused to the lens. The rings pressed into the prismatic lens serve to correct this trouble to a considerable degree, and focus all rays at approximately the same distance from the lens.

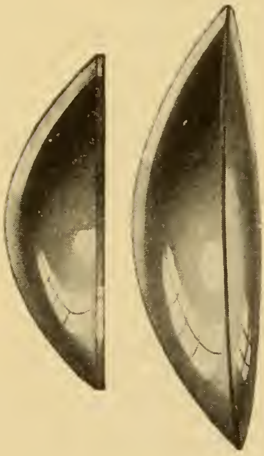


Figure 164

Older type filament lamps were operated with a 2-lens plano convex condenser. The newer types use either (199) the prismatic condenser shown in Fig. 163 or the more efficient aspheric lens.

The prismatic lens is a pressed lens which in the very nature of things cannot have as true and optically efficient a surface as that possessed by a ground and polished lens. Moreover the reflection loss of the prismatic lens (the angle of light incident being equal) is greater than that of the aspheric lens.

(200) The aspheric condenser, Figure 164, has a non-

spherical surface that also reduces spherical aberration. (201) The light source may be located close enough to aspheric condensers to deliver light through an angle of almost 100 degrees, as compared with about 60 degrees for the plano-convex combination, and with 78 to 80 degrees for the prismatic type. Manufacturers of projection-type filament lamps claim they gain increases of screen illumination of from 25 to 50 per cent over the prismatic and plano-convex condensers. However, the spacings between lamp and condenser and condenser and aperture must be adjusted to minute perfection.

The prismatic condenser, shown in Figure 163, because of its relatively short source-to-aperture distance, is still used in some portable projectors, where compactness is essential. (202) Aspheric condensers are not recommended or required for lantern slide and similar still picture projection. For stereopticon projection the plano-convex condenser is compulsory.

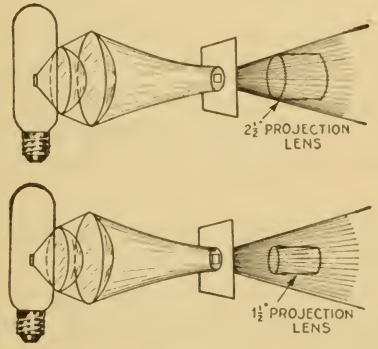


FIGURE 165

THE PROJECTION LENS

Since projection lenses are treated more fully elsewhere, they will be discussed here only in their relation to filament-type lamp projection.

(203) As will be observed by examining Fig. 165, with filament lamps the light beam diverges rapidly between the aperture and the projection lens. If the lens is to intercept most of the beam, the distance from aper-

ture to the rear element of the lens—which is fixed by the focal length of lens—and the diameter of the lens are two prime points to be considered.

Repeated measurements have demonstrated that the No. 2 or "half-size" projection lens, having a greater diameter, will pick up and send forward to the screen more than twice as much light as the smaller diameter No. 1, quarter size, lens of the same focal length. This difference would be greater were the comparison made between lenses of longer focal length, and smaller if the focal length were shorter, since the change of E.F. automatically affects the working distance, that is the distance from the rear surface of the projection lens to the aperture.

(204) Unfortunately, due to optical limitations, the No. 2 lens is not available in lengths below 4.5 inch E.F.; therefore, below that limit the No. 1 lens must be used. This is not so bad as it appears because the short focal length lens also has a short working distance and consequently it meets the light beam before it has diverged widely.

In any event the projection lens must pick up, as nearly as possible, the entire light beam. If it fails to do so the result is a needless loss in illumination of the screen. Whether or not the beam all enters the lens may be determined roughly by blowing smoke into it or by holding card at the back of the projection lens.

(205) Projectionists should insist that their lamp equipments be provided with No. 2 size projection lenses if they are available in the required focal length. Exhibitors and managers should be made to understand that without such lenses there will be a continuous waste of light which means a waste of electric power as well as lessened screen illumination. It is, in the end, a costly piece of business to force the lamp to work with a small diameter projection lens of 4.5 or more E. F.

Application Limits

Experience has thoroughly demonstrated the fact that, in general, the 900 watt, 30 ampere lamp, and the

2100 watt 60 volt lamp, properly adjusted, efficiently handled, and aided by proper lenses, etc., can be made to supply satisfactory screen illumination of a very pleasing nature on diffusive screens not exceeding 12 feet in width, or on specular screens not more than 16 feet wide, providing always the screen has a good reflection surface and is kept in good condition. This applies to all theatres where the seating capacity is 800 or less on the main floor, where the viewing distance does not exceed 75 feet, and where vertical and horizontal viewing angles are not too great for good results with the specular screen. The 2100 watt lamp employs the biplane filament form and doubles the light the screen could obtain from the 900 watt lamp.

SOUND EQUIPMENT AND SOUND

Practical Questions

(For answer to each question see statement of corresponding number in Chapter XV)

THE NATURE OF SOUND, PAGE 417

1. Is sound a physical object?
2. How can it be recorded?
3. What is recording?
4. What is the function of theatre sound equipment?
5. What has the nature of sound to do with the operation of theatre equipment?
6. What IS sound?
7. What is the effect of sound upon the human ear?

SOME CHARACTERISTICS OF SOUND, PAGE 419

8. What is frequency?
9. What is the relation between the pitch of a sound and its frequency?
10. What is volume?
11. What are harmonics?
12. Why are harmonics important?
13. What is resonance?
14. What is the range of frequencies audible to the human ear?

ELEMENTARY OUTLINE OF ACOUSTICS, PAGE 422

15. What is the speed of transmission of sound through air?
16. Is sound transmitted through air in straight lines, as light is?
17. What happens to sound when it reaches the wall of a theatre?
18. What type of material absorbs sound?
19. What is echo?
20. What is reverberation?
21. Name three cures for reverberation.
22. Name four cures for echo.

CHAPTER XV

SOUND EQUIPMENT AND SOUND

Theatre sound equipment is an apparatus of many parts designed for reproducing recorded sound.

(1) What is recorded sound? Sound cannot be put away in a box and taken out again when wanted; it is not a physical object, but, rather, something that happens to physical objects. It is a condition of highly temporary vibration. This condition cannot be caught and put away, but while it lasts (2) it can be compelled to perform work in the creation of a record. By means of the record so created a new sound may be produced in the future that will exactly resemble the original sound.

(3) The work performed by the original sound is "recording." The creation of a new sound that exactly resembles the original is "reproduction."

(4) Theatre sound equipment is an apparatus of many parts designed to create sounds that will exactly resemble other sounds heard previously in a recording studio.

(5) In order to understand how such equipment operates it is necessary to have some simple knowledge of the nature of sound, and of the work it performs while it is recorded.

NATURE OF SOUND

(6) An ordinary electric buzzer creates sound when its flexible element vibrates, but at no other time. Sound is created when the strings of a violin vibrate, but not when they are motionless. It seems reasonable to suppose that the vibration of a physical object disturbs the particles of air with which it is in contact, causing them also to vibrate. These particles in turn

are in contact with other particles, which, of course, will be similarly disturbed. The area of agitation of the air must spread outward in every direction from the source of vibration, losing energy with increasing distance from that source.

That sound does consist of an agitation of the air, which in turn affects the human ear, can be shown by sealing an electric buzzer in an air-tight glass container and pumping out the air. The sound of the buzzer becomes weaker as the air within the glass becomes thinner, but it is easy to see that the action of the buzzer itself is in no way changed. If the pumping be continued the sound completely disappears, although the buzzer continues to vibrate as strongly as ever.

Surgeons long ago examined the human ear and learned that it contains a membrane of flesh stretched across the opening in such a way that it must vibrate if the air in contact with it does so. (7) From the human point of view, sound is a vibration of the eardrum caused by the periodic increase and decrease of the pressure of air against it. Let us examine this action in somewhat greater detail.

Consider the fraction of a second during which the armature of a buzzer is moving from left to right. All particles of air to the right of the armature will receive a shove and move towards the right until they collide with the next adjoining particles of air in that direction. These next particles are in turn forced ahead for a short distance. until they also lose their energy by similar collisions, in which they push ahead still other particles. At the end of some distance the pushing process reaches some particles of air in contact with the elastic drum of a human ear, forcing the drum to bend inward.

But meanwhile the armature of the buzzer, having completed its motion to the right, has reversed and begun its move leftward, whereupon for a brief instant of time a vacuum exists to its right. Those particles of air nearest the buzzer which a moment ago had been pushed rightward, now rush toward the left to fill that vacuum, leaving a vacuum behind themselves into which air still further to the right must be drawn. The chain of events is now precisely the reverse of that which existed a fraction of a second previously. At the end of the process that particle of air which an instant before had been driven against the eardrum is sucked backward by the sudden appearance of a vacuum behind it, and the eardrum which had just been bent in is now sucked outward. An instant more and the buzzer armature moves to the right again and the cycle of events just described is repeated. It may be repeated several hundred times, or several thousand times, in one second, according to the construction of the buzzer.

PITCH OF SOUND; FREQUENCY OF VIBRATION

If a calling card is held against the teeth of a revolving gear, the edge of the card will act in much the same way as does the vibrator of an electric buzzer. As each tooth strikes against the card its edge is urged forward. When the tooth has passed, the elasticity of the material causes the edge of the cardboard to spring back. As long as the gear continues to revolve the edge of the card will vibrate, just as the armature of the buzzer did.

(8) Now the frequency with which the edge of the cardboard moves can be altered very easily by changing the speed of the gear. Moreover the speed of vibration can be calculated. If the number of teeth in the gear are counted, and its speed of rotation measured, finding out how many times the card moved backward and forward in one second is a matter of simple arithmetic. Thus the frequency of vibration of any sound—the number of cycles of changes of air pressure per second—might be determined by changing the speed of a revolving gear until a similar sound is created by a vibrating card or reed.

If the speed of the gear be increased the pitch of the sound created by the card becomes higher. If the gear slows down, the sound created bv the card becomes lower in pitch.

(9) High pitch of sound = high frequency of vibration (many vibrations per second).

Low pitch of sound = low frequency of vibration (few vibrations per second).

VOLUME OF SOUND; STRENGTH OF VIBRATION

(10) It seems logical to believe that the intensity or volume of sound corresponds to the intensity or extent of the changes in air pressure. Experiments can easily be made to prove this is true. Slight change in air pressure means weak sound and vice versa.

FUNDAMENTAL AND HARMONIC

Let us for a moment return to our vibrating card held against a revolving gear. We have said that the frequency of any sound *might* be determined by means of a toothed wheel and a flexible card. That is true, but the method would not be a very good one. Consider the action of the card edge in somewhat greater detail. When a tooth strikes it the edge is moved forward. After the tooth has passed the natural elasticity of the material causes the edge to spring back; true, but that is not all that happens. The edge of the card does not merely spring back to its original position and remain there rigidly awaiting the next tooth. It springs back a little beyond its original position, and then vibrates back and forth for a brief time before finally coming to rest, all of which occurs between the contact of one gear-tooth and the next. That small secondary vibration while the edge of the card is coming to rest will create a second, weaker sound to accompany the main or fundamental frequency. Because it all takes place between one gear tooth and the next the secondary vibration will be faster—higher in frequency and pitch—than the fundamental vibration.

(11) Such secondary motions exist in nearly all vibrating objects. The secondary sounds accompany most of the sounds we normally hear. One small part of a violin string will vibrate at a much higher pitch

than the string as a whole, thus creating a secondary sound to accompany the fundamental.

Such secondary sounds are commonly called harmonics, while the chief sound or frequency is called the fundamental. Pure sounds, without any harmonics, can be created by means of a tuning fork or by electrical means. "Pure" sounds are commonly recorded on test films or test records, but the sounds of ordinary speech and music are normally very rich in harmonics or "overtones."

HARMONICS AND CLARITY

(12) If a violin and a piano both play the same note, both are creating fundamental vibrations of the same frequency, and the ear could not tell one instrument from the other were it not for the overtones that accompany the fundamental. When two people sing the same song in the same key of music, only the overtones make it possible to distinguish between their voices.

Recording and reproducing equipment must deal faithfully with the harmonics as well as with the fundamental vibrations of sound.

RESONANCE

(13) If the edge of a moving card vibrates with the frequency of, say, 200 cycles per second, and a violin is held near-by, the G string of the violin may vibrate in resonance. Each time the edge of the card moves toward the string, the string is driven backward by a wave of air pressure; when the vibrating edge moves away from the violin the string is sucked forward by a reduction of air pressure. If the string is so "tuned" that its inherent elasticity permits it to vibrate at 200 cycles per second it will resonate, or keep in step, with the motion of the card. But if the tuning, the elasticity, of the string is not such as to reverse its direction of motion at precisely the same time that the air pressure changes, the motion of the string will get out of step with the changes of air pressure, and resonance will not exist.

Frequency Range of Audibility

(14) The human eardrum is so constructed that its natural elasticity will permit it to respond to any sound between, roughly, 16 and 16,000 cycles. Sounds outside that range cannot, in general, be heard by the human ear. The exact range differs rather widely with different individuals; it also changes with increasing age. The ear is most sensitive to sounds around 1,000 cycles. The very high-pitched and very low-pitched sounds require more volume to make them audible to us.

Transmission of Sound

Sounds can be heard under water. An ear placed against a wall will hear vibrations in that wall that are not audible in the neighboring air. Very many substances are capable of vibrating at the audible frequencies. In other words, they are capable of transmitting sound. But in practical theatre work we are concerned chiefly with air as a medium of transmission.

(15) All sound vibrations, regardless of their frequency, are transmitted through air at a rate of about 1,000 feet per second. The speed varies slightly with temperature and moisture. It is generally somewhat more than 1,000 feet per second (closer to 1,100 feet) but the number first given will be sufficiently accurate for all practical acoustic work the projectionist is ever likely to encounter, and it is very easy to remember.

(16) Some frequencies of sound seem to radiate from their source in straight lines much as light does, and constitute beams of frequencies that can only be heard when one stands directly in the line of the loud speaker. But a very large number of frequencies wrap themselves around obstructions much as a ripple in water will wrap itself around a rock. It is not difficult to convey understandable sound to every seat of a theatre, but to provide every seat with its full share of all frequencies, including those that tend to travel in straight beams like light, is sometimes not at all easy.

It often calls for much prolonged and patient work in pointing and repointing the speakers.

REFLECTION OF SOUND

(17) When an air wave strikes against the human eardrum it bends the drum inward, but if that organ were rigid and could not bend, the wave would have to rebound from it, and thus begin a wave of reflected sound. This happens when sound strikes the wall of a theatre unless that wall has been treated with "sound-absorbing" material. Such material may consist of thick drapes, of special plaster, or of anything (18) that contains a great number of very narrow air channels into which the vibration penetrates and is lost by reason of the friction between the particles of air and the extremely confined passages in which they must move.

The sound-absorbing power of acoustic drapes or plaster is not, however, the same at all frequencies. Consequently great care is required in choosing absorptive material for "acoustic treatment" of an auditorium, and such treatment is, in general, best left to acoustic experts.

Sound is reflected from a hard, smooth wall in the same way that light is reflected from a mirror—at the equal but opposite angle. But except for those frequencies that tend to travel as beams the reflected sound, like the original, will spread and wrap itself around obstructions and corners.

(19) A mirror presents a smooth, very close-grained surface to the minute waves of light, and therefore reflects a precise image. White plaster, although it reflects light, still is rough in comparison to the size of the light-waves and diffuses them so greatly in the process of reflection that no image is recognizable. The waves of sound are enormously large in comparison with the waves of light. A smooth plaster wall may reflect them with no appreciable distortion. The result is that the reflected sound is heard a fraction of a second after the original sound. This is echo.

The reflecting surface responsible for echo in a theatre can sometimes be located by timing the interval between the direct and the reflected sound, remembering that both travel at approximately 1,000 feet per second.

REVERBERATION

(20) Just as a plaster wall presents a rough surface to the waves of light, and distorts them in reflecting them, so a wall broken up by doors, columns or other large irregularities will distort the sound it reflects until it is no longer recognizable as an image of the original sound. Music or words cannot be distinguished. This form of reflected sound is called reverberation. Moreover, repeated reflections from even the smoothest walls and ceilings will also cause reverberation. It is a very common and very troublesome fault in theatres. Echo, as we can now see, is merely one type of reverberation—that type in which the sound is not distorted by reflection.

(21) The easiest remedy for reverberation is to use the lowest possible volume. Most theatre sound is much too loud. (See Chapter 25.) The next easiest is to point the speakers away from the reflecting surface and toward absorbing surfaces—such as the audience itself. The most troublesome and expensive remedy, but the surest, is to install drapes or acoustic plaster over the reflecting surface. Re-plastering should always be directed by an acoustic consultant; it is too expensive an operation to experiment with.

(22) Since echo is merely a special form of reverberation (that form in which the reflected sound is not distorted) it is treated by any of the methods just mentioned. In addition, it can be attacked by breaking up the reflecting surface through use of coffering (artificial recesses in the wall or ceiling). This last will cause distortion of the reflected sound and convert the echo into reverberation, which is the lesser of the two evils.

RECORDING AND REPRODUCTION

Practical Questions

(For answer to each question see statement of corresponding number in Chapter XVI)

The Nature of Recording, page 426

1. What is the relation between action of the human eardrum and the action of one important portion of recording equipment?
2. Why is the old-fashioned, familiar *mechanical* phonograph worth consideration in a study of electrical recording and reproduction of sound?

Early Methods of Recording, page 426

3. Describe the recording action of the old-fashioned phonograph.
4. What two types of record did it make?
5. Describe its action in reproduction.

Problems of Recording, page 426

6. Why is turn-table speed very important?
7. What is flutter?
8. What is hunting?
9. Can a record to create sound be made without the help of any previously existing sound?

Modern Methods of Recording, page 426

10. Why does theatre work require *electrical* recording and reproduction?
11. Outline the method of recording and reproducing sound electrically.
12. What two basic types of sound-track are created by electrical recording on motion picture film? Identify them in Figures 166-166E.

CHAPTER XVI

RECORDING AND REPRODUCTION

From what has been said it should be clear that the recording and reproduction of sound, once the fundamental nature of sound is understood, does not present any remarkable difficulties. (1) It has been explained that "from the human point of view sound is a vibration of the eardrum caused by the periodic increase and decrease of the pressure of air against it." Substitute a properly designed mechanical eardrum (a suitable diaphragm of metal instead of flesh) and the vibrations that constitute sound may readily be scratched in moving wax, photographed on a moving film, used to magnetize sections of a moving wire, or in fact recorded in a great many ways. Long after the sound has performed its work and died away the record can be used to operate some form of small air-pump, as, for example, a head telephone or a loud speaker, and thus re-create the identical sequence of changes in air pressure at another time and place.

How simple it really is to accomplish this may be made more clear by considering the old-fashioned mechanical phonograph. (2) In fact it will be worth our while to give that obsolete instrument some brief consideration. When a few simple mechanical details have been gone over and are out of our way, we can proceed to study modern, electrical recording and reproduction with disc or film, and then only the electrical principles involved with need detailed attention.

Early Methods of Recording

In this contrivance the essential recording element is a small disc of metal constituting an artificial eardrum. This, much like the drum of the human ear, is so mounted that it is free to vibrate in resonance with changes of air pressure carried to it by a horn or megaphone. Consequently, when sound (air) vibrations impinge upon this disc it will bend inward and bulge outward in resonance with the frequency of the sound, precisely as does the human eardrum, and for precisely the same reasons.

(3) A metal needle or stylus is rigidly attached to the center of the disc, so that every vibration the disc undergoes must be duplicated by the point of the needle. The needle may be mounted above a turn-table and on this turn-table may be placed a very thick, blank phonograph record made of soft wax. The turn-table is made to rotate at some fixed, unvarying speed, the needle is lowered until it cuts into the moving wax. Since the needle, together with its disc or diaphragm, is mounted upon a worm gear which moves it slightly sidewise at each rotation of the wax, it cuts a spiral groove, as may be seen on any phonograph record.

Now whenever sound waves reach the little metal diaphragm the point of the stylus must vibrate in resonance with them. In most recording this vibration causes the groove cut by the stylus to waver slightly from side to side. (4) Some records are so made that the vibrating point cuts deeper or shallower, creating what is known as "vertical cut" or "hill and dale" recording. The fundamental principle of "hill and dale" is, incidentally, not new. It is older than the other, or lateral, cut, but has recently been improved to give strikingly superior results. Whichever method is used the wax is engraved with a series of physical markings that corresponds exactly to the sequence of changes in air pressure. The slight variations in the groove cut by the stylus are the work the sound performed while it lasted, and by means of them a duplicate of that sound can be created at any time after the record has been made permanent. This is done by dusting the wax with carbon powder and electroplating metal upon it.

Assume that the wax has been so treated, and the resultant metal perhaps used to manufacture many similar records through a stamping process. (5) Then the same equipment that made the record will serve to play it back. The permanent record is placed under the stylus, the turn-table is rotated again at the same speed as before, and the needle is allowed to follow the groove it made while it was acting as a recorder. When the point of the needle encounters the small variations cut in the groove it must vibrate; its vibrations will be communicated to the diaphragm; the diaphragm must vibrate and impart its vibrations to the air around it, and a reproduction of the original sound will be heard.

Turntable speed, however, needs accurate control. (6) The reproducing speed must be identical with the recording speed. Suppose that at a certain low note the needle cuts a hundred variations in the groove in a second's time. Then, during playback, the needle must encounter a hundred deflections of its course through the groove during the same interval of one second. Otherwise the note played back would be either higher or lower in pitch than the original note.

(7) Moreover, the speed of rotation, during recording and playback both, must be constant, otherwise the pitch of the sound will change, or "flutter." (8) A slow flutter, slow change in turn-table speed, is called "hunting."

(9) A record, whether disc or film, need not necessarily be a record of actual sound. Test records and films are sometimes made by purely electrical means, which cause the needle or the light-shutter to vibrate at any desired frequency, without the existence of sound in the air at all.

Modern Electrical Recording

Old fashioned disc recording did not provide sufficiently high quality, largely because (10) the same diaphragm could not be made sufficiently sensitive to intercept the weaker sounds and at the same time rugged enough to force the needle to record those of maximum strength. In modern electrical disc recording (11) the diaphragm is merely that of a microphone, and the microphone currents are amplified before being used to drive the cutting needle or stylus. Disc recording still is quite commonly used, with re-recording from disc to film sound track.

In film recording the microphone currents operate a light valve instead of a cutting stylus. There are many varieties of sound track, all derived from two fundamental types. Those two are shown in Figs. 166-166E and 167-167B, each a typical sample.

(12) In making v. w. tracks, the microphone current controls the oscillations of a tiny vibrating mirror; the number of vibrations per second, (as represented by the number of transparent peaks recorded on each inch of sound track) represents frequency. The extent of the swing of the mirror, as represented by the distance the said peaks extend across the width of the sound track, records volume or loudness.

The v. d. type of track is made with a vibrating light valve consisting of thin ribbons of duralumin. The number of ribbon vibrations per second of time governs the number of variations from light to dark per inch of sound track. The extent of ribbon vibration controls the difference in shading, which represents volume.

The track of Fig. 166C is also called the "Constant Density, Variable Area" type. That shown in Fig. 166 is the "Constant Area, Variable Density" type.

To avoid the photo-cell hiss always heard with earlier recordings during periods of low volume or of no sound, modern tracks embody modifications that limit the area of film transparency to just what is required by the recording, and no more. As may be seen at the top of Fig. 166C, an adjunct to the light valve automatically narrows the clear portion of the track during periods of low volume. All of the tracks shown in Figs. 166A-B-C-D and E (in fact all but 166 itself) contain some similar provisions for "noiseless" recording. When such tracks are played, the photocell receives just sufficient light to reproduce the sound volume recorded. The background of hiss is therefore always so much weaker than the sound that it is inaudible.

Constant density tracks are now recorded with invisible ultra-violet, instead of with white light. Ultraviolet can be focused more sharply than can the longer or visible waves lengths of light. Consequently it provides a sharper outline at the top of each point in Fig. 166C, thus making for more accurate recording.

Figs. 167, 167A and 167B are push-pull tracks, each half of the cell receiving the illumination that is transmitted through one of the double tracks. In contrast to the double tracks of 166 B-D and E, the paired push-pull tracks are 180° out of phase; in them, the lighter area of one track is opposite the darker of the other.

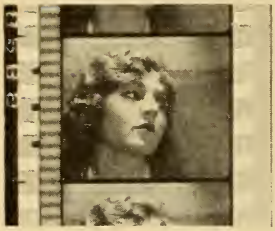


Fig. 166. Single variable density.

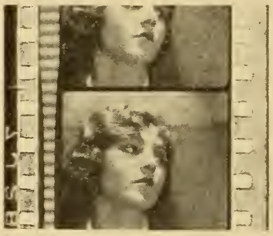


Fig. 166A. Single variable density squeeze.

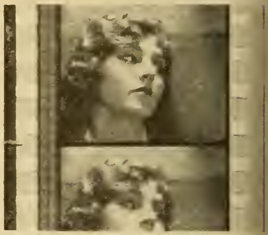


Fig. 166B. Single variable density double squeeze.

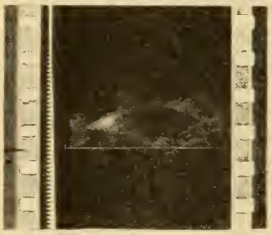


Fig. 166C. Unilateral variable width.

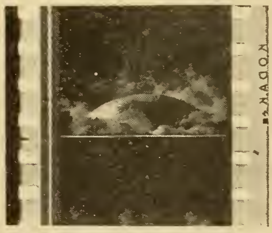


Fig. 166D. Bilateral variable width.

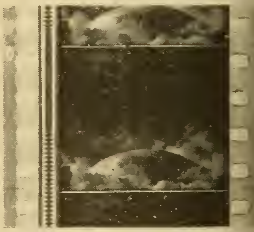


Fig. 166E. Duplex variable width.

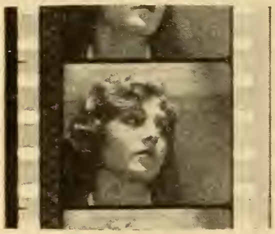


Fig. 167. Push-pull variable density.

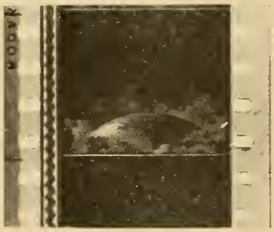


Fig. 167A. Push-pull variable width.

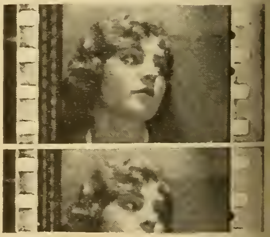


Fig. 167B. Push-pull variable density squeeze.

(Above illustrations from publications of Research Council, Academy of Motion Picture Arts & Sciences)

THE A.C. TRANSMISSION LINE

Practical Questions

(For answer to each question see corresponding number in text of Chapter XVII)

IMPEDANCE MATCH, PAGE 432

1. Name an important requirement in a circuit carrying a.c.
2. Explain the necessity for impedance match.
3. Why is impedance match of especial importance in sound circuits?
4. Where and why may impedance mis-match be intentionally introduced into a sound system?
5. At what frequencies are impedances matched in sound equipment?

FREQUENCY FILTERS, PAGE 434

6. How may low and high frequencies in the same wire be separated?
7. What is a "low-pass filter"?
8. What is a "high-pass" filter?
9. How can the selective effect of a filter be modified?
10. How are low-pass and high-pass filters used in sound apparatus?
11. Describe a "resonant circuit."
12. What are "band pass" filters?
13. Which type of filter is commonly found in the modern projection room?

CHAPTER XVII

THE A C TRANSMISSION LINE

(1) When a. c. is transmitted over a pair of wires, one of the most important requirements of the circuit is that the impedance (see Page 30) of the apparatus from which the current comes shall match the impedance of the apparatus to which the current is led.

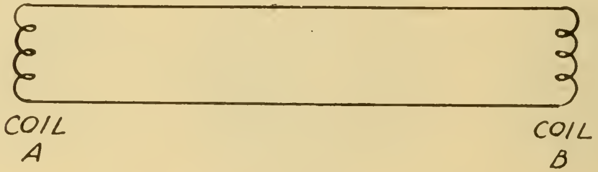


FIGURE 168

IMPEDANCE MATCH

Figure 168 represents a very simple a. c. transmission line, in which we assume that the source of the current is coil A. Coil A may be, and in sound equipment usually is, the secondary winding of a transformer. Coil B may be the speech winding of a loud speaker or the primary winding of an input transformer or other apparatus. In any case, the impedances of A and B should be identical. There are a very few exceptions, none of which need concern the projectionist.

(2) We can most easily understand the necessity for impedance match between A and B by assigning numerical values to their action. Let us assume that A has an impedance of 1000 ohms and that it is the secondary of a transformer developing 100 volts. Now assume that the impedance of B also is 1000 ohms. Let us calculate the amount of power transferred from A to B.

The total voltage of this circuit is 100, of which 50 volts is consumed by the loss or drop in coil A. Therefore, neglecting the resistance of the connecting wires, 50 volts must be the drop across coil B. The circuit current is, by Ohm's Law (100 ÷ 2000 ohms), 1/20 of an ampere. Then the power in coil B can be taken as 1/20 of an ampere times 50, or 2½ watts.

Now the reader may please himself by assigning other impedances to B and he will find that no impedance except that which equals the impedance of coil A will give him as much as 2½ watts in coil B. By trying one or two examples we will easily see the reason for this. Suppose we make B 500 ohms. Then the total impedance of the circuit is 1500 ohms and the current flowing is, by Ohm's Law, 100 divided by 1500, or 1/15 of an ampere. 1/15 of an ampere is a larger current than 1/20 of an ampere. We now have more current in coil B than before, but let us see about the power. Coil B now has only 1/3 of the total impedance of the circuit and the voltage drop across it is only 33 1/3 volts. If the reader will apply elementary arithmetic to these figures he will find that the power in coil B is now only 33 1/3 multiplied by 1/15, or 2 2/9 watts. The current flow through B has been increased but the voltage drop across coil B has been reduced, and the power in any resistor is the current flowing multiplied by the voltage drop.

If, on the contrary, we make B 2000 ohms, then there is a 66 2/3 volt drop across B. But the increased impedance has reduced the current flowing in the circuit to 1/30 of an ampere, and the power in B is again only 2 2/9 of a watt. The reader may make as many other calculations as he cares to, assigning any value of impedance whatever to coil B. He will invariably find that either the decreasing current in coil B or the decreased voltage drop across it reduces the power in that winding to some figure less than the 2½ watts obtained when the impedances were accurately matched.

(3) Impedance match is of great importance in sound systems, where the alternating currents representing speech are often extremely minute and any loss

of power anywhere in the system seriously reduces the volume that can be obtained from the loud speaker. (4) In a few systems a variable impedance mis-match is intentionally introduced as a means of volume control, and for other purposes, such as control of the frequency response of the system.

The impedance of an a. c. circuit is partly a matter of the reactance, that is, of the resistive effects of inductors or capacitances. Now the reactance of these devices varies with different frequencies of alternating current, and sound currents may be of any frequency between 16 and 16,000 cycles per second. Therefore it is not always possible to match impedances for all sound frequencies. (5) A practical compromise is effected in sound apparatus by matching impedances over the widest possible band of those frequencies to which the ear is most sensitive. The impedance rating of any piece of sound apparatus commonly means the impedance of that part to a. c. of either 400 or 1,000 cycles, according to the practice of its manufacturer. Then its impedance to 500 or 1,500 cycle current will not be very much different, while its impedance to currents of 100 or of 10,000 cycles may be distinctly different.

The highest possible quality and efficiency are obtained by carefully maintaining impedance match at some central and important frequency, such as 1,000 cycles, except where an intentional and carefully calculated mis-match is introduced for some such purpose as reinforcing or suppressing a selected band of frequencies.

FREQUENCY OR BAND FILTERS

(6) Electrical filter circuits can be arranged to separate low and high frequency components. Suppose the d. c. generator in Fig. 169 to be replaced by an a. c. source capable of delivering both low and high frequencies. It is obvious that more of the lows than of the highs will get through to the load resistor. The values of the inductor and the condenser can be so chosen that a very

large part of the low frequency power will reach the load resistor. As the frequency becomes higher, the power will be increasingly shunted through the condenser. Such an arrangement is called (7) a low pass filter. It can be reversed. (8) Suppose that in Fig. 169 the condenser were in series with the load, and the inductor in parallel to it. The result would be that the load would receive a preponderance of high frequencies, and the arrangement would be called a high pass filter.

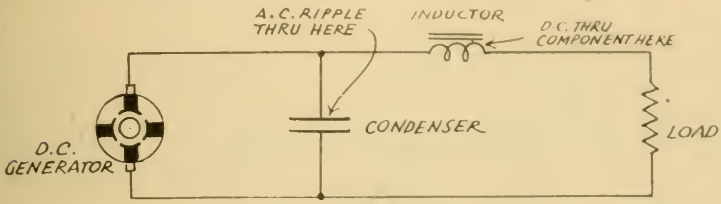


FIGURE 169

(9) The selective effect of such filters can be modified by inclusion of a variable resistor. (10) When so modified they are used as tone controls. Various forms of selective filters are quite common in sound systems.

Fig. 170 represents one very common form of amplifier tone control. The condenser, with its resistor in series, short-circuits more or less of the high frequency power, the exact degree of h. f. loss depending upon the resistor setting.

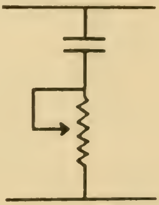


FIGURE 170

(11) A filter circuit including both inductance and capacitance can be made electrically "resonant." The rhythmic rise and fall of the inductor field and the periodic charge and discharge of the capacitance cooperate to produce a "tuned" effect at some one frequency. (12) If wired so as to pass a single frequency only, such a circuit is a band pass filter; it may also be wired to oppose only one frequency, and then is called a band stop filter. Filters can be built to exhibit maximum effect upon a single frequency, or to have approximately the same effect upon all frequencies within a chosen band.

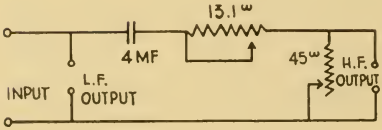


FIGURE 171

(13) Very common, in modern systems, is a network of the type shown in Fig. 171, which is essentially a combination of low pass and a high pass filters.

It has been found that better quality is obtained by designing separate loud speakers to handle the low and high frequency sound components, rather than by trying to force one speaker to give satisfaction on both bands. The speech currents supplied to the loud speakers accordingly are divided by a filter network.

In Fig. 171 the low frequency speakers are connected directly across the amplifier output. They constitute what is essenially a choke coil wired in parallel to the L. F. output terminals of that diagram. The high frequency speakers, however, receive only such components as are able to reach them through the 4 microfarad condenser. (The two resistors constitute a pad for controlling H. F. volume.). Fig. 171 is a very simple form of network.

Fig. 172 is an elaboration of it. Here the H. F. supply path is traced right through 2 microfarads, down through the H. F. output terminals, at the left, and on through 4 microfarads to the other side of the amplifier output. It is aparent that the load is short-circuited so far as *low* frequencies are concerned, by the choke coil between the two condensers. The low frequency path is traced down through that choke coil, and thence to the l. f. speakers; those speakers being short-circuited for high frequencies by 4 micofarads. This arrangement is elaborated in Fig. 173.

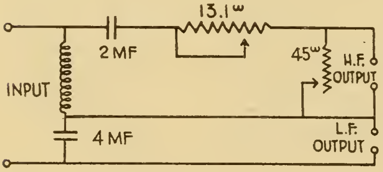


FIGURE 172

Where Fig. 173 is used with a single power amplifier the two left-hand input terminals are wired together, as indicated by the dotted line, and connection is made to either of them and the input common, marked C. When so connected, its circuit is similar to that of 172, except for the addition of the series choke coil at the bottom left of the drawing. Fig. 173 may also be used in systems having separate output amplifiers for low and high frequencies. In that case the jumper represented by the dotted line is eliminated and each amplifier wired to its own input.

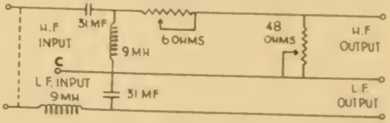


FIGURE 173

Fig. 174 is a diagrammatic representation of the way Fig. 173 performs.

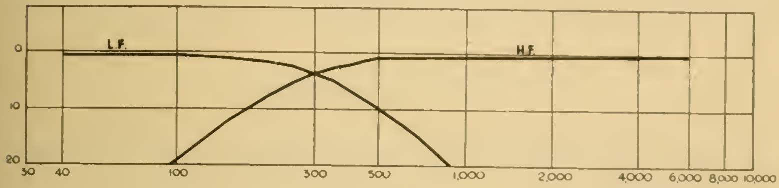


FIGURE 174

COMPONENT PARTS OF A SOUND SYSTEM

Practical Questions

(For answer to each question see corresponding number in text of Chapter XVIII)

1. Why is a sound system frequently divided into many different panels and cabinets?
2. Does this division correspond to technical differences in the nature of work performed?
3. Divide a sound system into six parts according to the technical functions of the apparatus.

The Sound Pickup, page 441

4. What is the function of the photoelectric cell in a sound system?
5. Name two other sources of sound current.

The Transmission Lines, page 441

6. What is the function of transmission lines in a sound system?
7. Are they found inside as well as outside amplifiers or other apparatus?
8. What is the minimum number of external transmission lines in any sound system?
9. Can ground be used as one side of a transmission line?

The Amplifiers, page 442

10. Does an amplifier act to convert weak currents into strong ones?
11. Is the output current drawn from an amplifier only the input current made stronger?
12. When speech current is supplied to an amplifier, does it complete its circuit back to its source as ordinary currents do?
13. Describe in outline the process of amplification in an amplifier of several stages.

14. What apparatus in an amplifier functions as an electrical valve, or controller?

THE SPEAKERS, PAGE 444

15. Explain the difference between a loud speaker and an ordinary electric motor.

THE POWER SOURCES, PAGE 444

16. What types of electrical power are required by sound systems?
17. Are they obtained from ordinary line a.c.?
18. Name two classes of circuits found in a modern amplifier.
19. Why do sound reproducing systems require a mechanical drive?

THE DRIVES, PAGE 445

20. Name some of the devices in a sound installation that may be classified under the heading of "The Drive System."

CHAPTER XVIII

COMPONENT PARTS OF A SOUND SYSTEM

In studying the application in a practical sound system of the theories already outlined and of one or two others still to come, it will be exceedingly helpful to divide up the sound apparatus into its component parts. Such division will not necessarily follow the manufacturer's division of his equipment into different panels, cabinets, etc.

(1) The manufacturer splits up his equipment into small units primarily for the convenience of the projectionist, but also to facilitate shipment and installation. (2) He does not divide it in accordance with the technical uses of the parts, but rather for the comfort of the expressman; to secure convenient layout in the projection room, and to make repair or replacement as simple as possible. In studying the functioning of any given installation of sound equipment the projectionist will find it advantageous temporarily to forget its physical division into cabinets or panels and to concentrate upon an electrical whole subdivided, in his mind, according to the functions the different parts perform, regardless of whether two parts that do the same work are in different cabinets or whether two parts that do different work are in the same cabinet. Later, when he is thoroughly familiar with the theory and behavior of every portion of his equipment, he will reap great advantage in trouble-shooting by considering the manner in which the system is divided up physically, and the most convenient points for reaching connecting terminals to which test instruments can be applied.

For the present, we are concerned with dividing up the cumbersome whole of a sound system according to the different services performed by its different parts.

From this point of view any sound installation consists of six parts, which are (3) as follows: (a) the sound pick-up; (b) the transmission lines; (c) the amplifiers; (d) the speakers; (e) the power supply; (f) the drive system.

THE SOUND PICK-UP

(a) This consists of any or all sources of sound currents which are to be amplified and converted into sound by the loud speaker.

The most common of these is the photo-electric cell. (4) This cell acts to produce sound currents corresponding with the variations of light and darkness photographed upon moving film. Its action is described in greater detail in Chapter XX. (5) Another source of sound power is the disc reproducer or phonograph pick-up which creates currents that correspond to the irregularities of the groove engraved upon a phonograph record. Less common than either of these in theatre use is the microphone which is an instrument creating currents that correspond to any vibrations in the air that is in contact with its diaphragm. All these devices are explained more thoroughly on appropriate pages.

THE TRANSMISSION LINE

(b) Some of the electrical principles involved in the action of an a. c. transmission line were described in the preceding Chapter. (6) Transmission lines are part of every sound system. They receive the current produced by the sound pick-up and carry it to the amplifier, with perhaps an intermediate stop at a change-over device or volume control. They carry the sound output of the amplifier to the speakers. (7) The interior of the amplifier contains, between its various parts, transmission lines which are electrically similar to external transmission lines, since wires carrying sound currents within the amplifier are subject to the same rules as wires carrying sound currents from one amplifier to another, or from an amplifier to a loud speaker.

Internally as well as externally impedances must be correct and frequency filters may or may not be inserted.

(8) The simplest possible sound system will have at least three external transmission lines: namely, one from each photo-electric cell to the amplifier and one from the amplifier to the loud speaker.

(9) Ground is sometimes used as one side of a transmission line, that is, as one of the two wires of the circuit. This procedure was formerly rather common in photo-electric connections.

AMPLIFIERS

(c) As we have already seen by several examples, the same electrical action can be looked upon in two different ways, according to convenience; and one of these ways of regarding any electrical action, even though known to be wrong, may still be useful for some purposes.

(10) In describing the action of amplifiers it is incorrect, but convenient, to say that an irregular alternating current, which corresponds in its various frequencies to waves of sound, enters an amplifier as a weak current and emerges from it strengthened, or "amplified."

The above statement, although very often made, is not strictly correct. It describes quite accurately what an amplifier does, but it gives a completely false impression of how the amplifier does it.

It is quite true that a weak alternating current enters the amplifier, and that a much stronger alternating current can then be taken from the output end. It is also true that the output current reproduces very nearly, and sometimes almost exactly, the input wave-form. (11) But the output current is not the input current made stronger. Instead, it is a totally different current, flowing through an entirely separate circuit. Although the construction and functioning of amplifiers are described in great detail further along, it should be worth while to take time at this point to explain just what an amplifier does not do, as well as what it does.

We have just seen what it does not do. It does not make a weak current stronger. It does use a weak current to operate a very delicate valve by means of which a much greater amperage is turned on or off and increased or decreased. The result is that the fluctuations thus introduced into the flow of the heavier amperage represent an exact or nearly exact reproduction of the current fluctuations of the original or input circuit.

The details of how this is done belong in another place. We merely note here (12) that the sound current flowing into an amplifier completes a normal electrical circuit back to its source just as any other current does. (13) Only, while in transmission, it actuates a valve apparatus in which it is enabled to exercise a very delicate control over the flow of current in a circuit of greater power.

Let us agree to call the input circuit P and the heavier circuit Q. Then if further amplification is needed Q can be used to operate another valve and thus control a third, still more powerful circuit, which we will call R. And R, in turn, can be used to operate the trigger controlling a yet heavier current, and so on. The process can be and often is repeated six or seven times. Nevertheless P, Q, R and all the other speech currents in an amplifier each return to their own source unchanged, in the normal electrical way. The only essential difference between amplifier wiring and any other electrical wiring is that each speech current, as it flows around its circuit, is made to work against a valve in which it controls a stronger current.

(14) The valve, as it is called in England, is, of course, the tube. Our own word "tube" really means nothing except that the first devices of the kind, about twenty years ago, were built into long, slender tubes of glass instead of the bulbous glass or metal envelopes of the present day. If the reader cares to make a habit of thinking of amplifying tubes as valves, his understanding of their action may perhaps be clarified.

A modern amplifier contains many other appliances beside its tubes, but all other parts are merely assistant pieces, put there to help the valves carry out their function.

All the parts that go to make up an amplifier, with their separate purposes and their interconnections, will be described in full detail a little later on. Here we are primarily interested in dividing up a complete sound system into its constituent units, of which the amplifier is only one.

SPEAKERS

(d) The relatively powerful sound current drawn from the output circuit of an amplifier cannot be detected by human ears until it is converted into air vibrations of corresponding strength and frequency. (15) The apparatus that performs this conversion is the speaker, which is most easily understood by remembering that it is really an electric motor, driven by electrical power and producing mechanical power in the form of air waves. Most electric motors create mechanical power in the form of rotary motion. They turn a wheel. The speaker is a motor not designed to turn a wheel, but to actuate a piston. The piston, of course, is the diaphragm of the speaker, which operates upon the surrounding air at the frequency, and in accordance with the strength, of the current driving it. Speakers also will be described, in detail, in their proper place.

POWER SOURCES

(e) Every sound system requires power to operate it, (16) particularly direct current at both low and high voltages. Modern amplifiers often operate by simple connection to an a. c. power line, but a. c. at commercial line voltage does not enable them to perform their work, therefore (17) within the amplifier itself that power is converted to d. c. of suitable voltage and amperage.

Now, this work of power conversion is no part of the function of an amplifier. It is performed inside the amplifier casing only as a matter of convenience in construction and operation. In many of the earlier sound systems some, or perhaps all, of the power conversion is performed outside the amplifiers, which in such case have nothing to do except amplify. If the reader will always and invariably make this distinction in his mind he will find his study of amplifier circuits immensely simplified. He will then avoid any possible confusion between the amplifying valves and their attendant apparatus, which perform one job, and the power conversion apparatus, inside or outside the amplifier casing, which does another and entirely different piece of work. Later on, when we come to analyze amplifier drawings, this distinction will be made, since it will immediately simplify some of the complication of modern amplifier blueprints by dividing them in half, each half to be analyzed separately. (18) In working on modern amplifiers (trouble-shooting or repair) the reader will find it helpful to distinguish clearly between the speech circuits and the power circuits; doing so will take most of the difficulty out of his work.

DRIVES

(f) (19) The above classifications include all the purely electrical portions of a sound system, but leave the mechanical parts to be considered. Sound is a sequence of events that can be made to create a mechanical or photographic record. This record can be made to produce, or "reproduce," a very close duplication of the original sound, provided it is fed into the reproducing mechanism bit by bit, exactly as it was made and at exactly the same speed.

A phonograph needle takes sound from a record bit by bit, but the original sound will not be duplicated accurately unless the record is played at precisely the same speed at which the recording was made. The film that excites the photoelectric cell must likewise be run through the projector at exactly the same speed at which the recording negative was made.

When the sound system operates from a microphone it is reproducing original sound, hence no driving apparatus of any kind is required. But when it reproduces a record, whether film or disc, it requires a driving motor to move the record at precisely the proper rate of speed. (20) Gears or belts or shafts are employed to transmit the motor power. Special governors may be employed to keep the motor speed constant in spite of accidental changes in the voltage of the power line that drives it. Mechanical devices of various kinds keep the film moving smoothly and evenly before the photo-cell. All these contrivances, taken together, may be said to constitute the sixth, and perhaps the most important part, of a complete sound installation.

POWER SUPPLY FOR SOUND SYSTEMS

Practical Questions

(For answer to each question see corresponding number in text of Chapter XIX)

VARIETIES OF POWER NEEDED, PAGE 449

1. List roughly the varieties of electrical power needed to operate an average sound system.
2. Is a loud-speaker field ever operated by a.c.

METHODS OF PROVIDING POWER, PAGE 450

3. Are dry cells ever used to supply voltage for sound?
4. Why cannot power line d.c. be used to supply 90-volt d.c. to a photo-electric cell?
5. For what sound purpose can line d.c. be used, and how?
6. What auxiliary apparatus is used with a motor-generator supplying sound power?

HOW TO READ ELECTRICAL DRAWINGS, PAGE 451

7. What is the most convenient way to study a sound circuit?
8. What is a schematic drawing?
9. What is the difference between a schematic drawing and a wiring drawing?

RECTIFIERS, PAGE 454

10. What device is almost universally used to supply current and voltage in modern sound equipment?
11. Describe in outline a complete rectifier circuit supplying low-voltage d.c. from an a.c. source.

THE CARE OF TUBE RECTIFIERS, PAGE 455

12. What attention and care must be given to the relay contacts of a power supply rectifier?
13. What common electrical apparatus will serve as a temporary substitute for a defective filter part?
14. What will happen if one tube of a full-wave rectifier circuit burns out or becomes weak?
15. What will happen if a filter coil is short-circuited? If a filter condenser is short circuited? If a filter condenser is open-circuited?

THE MERCURY VAPOR RECTIFIER TUBE, PAGE 456

16. Explain in detail why a mercury-vapor tube is capable of rectifying greater amperage than a vacuum tube of the same size.

CHAPTER XIX

POWER SUPPLY FOR SOUND SYSTEMS

Nearly all the constituent parts of a sound installation require the application of electrical power of some kind, though the requirements vary considerably. Direct current at several voltages is needed, and more than one voltage of alternating current.

It will be advisable, for several reasons, to consider both the power requirements, and the methods used to meet them, before examining the apparatus in which that power is to be used. One of those reasons lies in the fact that (as has already been explained) the study of amplifier drawings is greatly simplified if the built-in power system can be recognized for what it is, and thus eliminated from any possible confusion with the amplifying action proper.

Varieties of Power Needed

(1) The list below must be taken as only a rough outline.

Exciting Lamps: d. c. or a. c., but most often d. c. Usually 8 to 12 volts, 2 to 4 amperes.

Photoelectric Cells: d. c. only. Usually 90 or 135 volts and only a minute fraction of an ampere.

Microphones: (Sometimes none) d. c. when used. Most commonly 1½ to 12 volts; less than ¼ ampere.

Drive Motors: a. c. where possible; line voltage, usually 110.

Amplifier "A": d. c. sometimes; a. c. usually. One to 10 volts; ¼ to 12 amperes.

Amplifier "B": d. c. always. Up to 1,000 volts; ¼ ampere. Occasionally still higher power.

Amplifier "C": d. c. always. Usually less than 50 volts; almost zero amperage.

Speakers: d. c. always. From 7 to 110 volts or higher: seldom more than 5 or less than 1/100 ampere. The above list represents the actual, or primary requirements, of average sound systems. Since power lines do not furnish electricity in such variety means of adapting the power supply to sound purposes must be installed in the projection room. (2) Power converters are often built into speakers, amplifiers, etc., as integral parts of those units, in which case a speaker, for example, may seem to be a. c. operated.

Dry Cells

(3) Dry cells are no longer used to supply any of the voltage or current requirements of sound systems, except in a very few amplifiers in which a special, acorn-shaped form of dry cell is used to supply "C" bias to the grids of amplifying tubes. This bias consists merely of voltage applied to a permanently open circuit. No current flows. Therefore the drain on the dry cell is zero. An ordinary dry cell of the flashlight type deteriorates even on the shelf because of slight impurities in its internal materials; but exceptionally pure materials are used in these special "C" bias cells and they maintain their voltage indefinitely.

Line D. C.

(4) Direct current from a commercial power line cannot be used for all d. c. power purposes. It is, for example, useful as a source of supply for speaker fields, but useless for photo-cell supply. The distinction is very simple. The photo-cell has amplification behind it; the speakers have not. Any sudden voltage changes, ripple or other unsteadiness in the power line would be amplified if that line were used to bias the photo-cell, and commercial d. c., being commutated a. c., always has some ripple. The same irregularity in the loud speaker supply does no harm since it does not undergo amplification. At worst, a condenser filter may be necessary to smooth the ripple

a trifle, and to take out the clicks caused by abrupt changes in voltage.

(5) In general, line d. c. can be used for sound power only in such connections as do not subject its inherent irregularities to amplification. In practice, this confines its use almost wholly to speaker field circuits, with or without the help of a filtering condenser, and often with the help of a rheostat to reduce the voltage to that required by the speaker, or by a number of speakers connected in series. The arc lamp d. c. supply from a rectifier or motor-generator can be, and sometimes is, used in the same way.

Motor Generators

One method of providing for the varied d. c. requirements listed above is to install a number of generators, which may be driven by either a. c. or d. c. motors, according to the power supply available.

(The fundamental principle of motor-generator action, and some details of motor-generator construction, will be found in Chapter VII. It does not seem advisable to go into further detail here. Books devoted to motors and generators can be found in public libraries, or may be obtained from publishers of electrical technical books.)

As used in the projection room for sound power purposes, motor-generators are usually small, light machines that can be switched on and off without necessity for any starting rheostat. (6) They are generally equipped with filters to eliminate commutator ripple. Filter, voltage regulating resistance, switches and fuses may be mounted in one "generator control cabinet" or may be distributed in several cabinets or boxes. In any case the connections represent only commonplace electrical circuits, and the projectionist should have little trouble in tracing and understanding those with which his own projection room is quipped.

Tracing Circuits

(7) It is always advisable to study an unknown cir-

cuit by means of a schematic, or skeleton drawing, which the manufacturer of the apparatus should be very willing to supply.

Figure 175 is the wiring diagram of the control box for a sound supply motor generator. To the beginner it may seem complicated, and difficult to understand or trace. (8) But let us look at Figure 176, which is the schematic or skeleton drawing of the identical circuit.

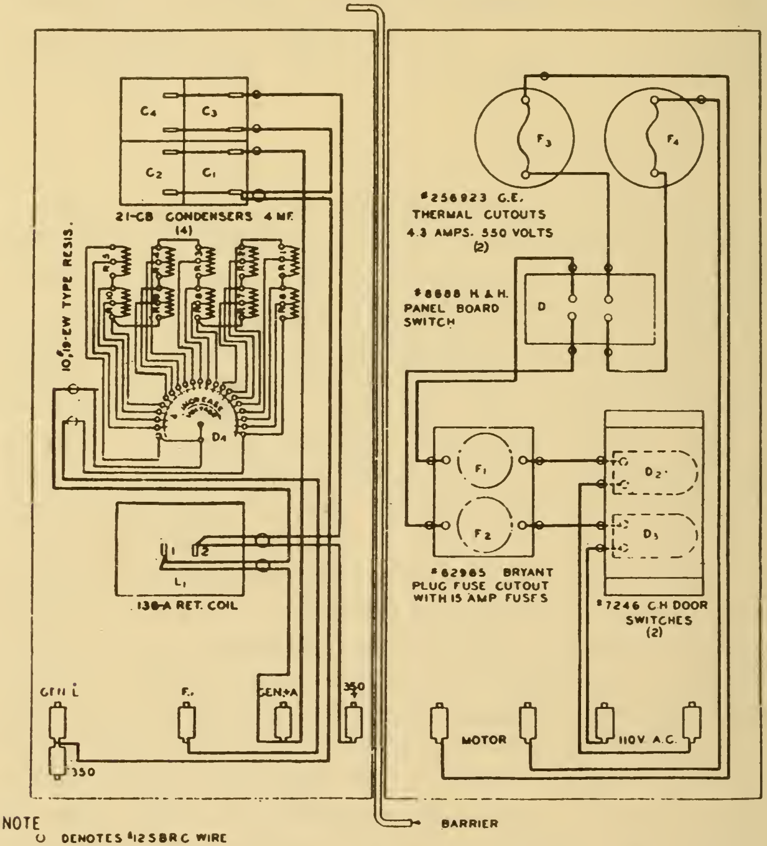


FIGURE 175.—Wiring diagram of control cabinet for sound supply motor-generator.

Figure 176 is about as simple and understandable as any such electrical arrangement can possibly be.

At its upper left hand corner are two terminals for the

110-volt a. c. wires that supply power to the motor of this motor-generator. Below are two switches so mounted on the cabinet door that they automatically break the power supply circuit when the cabinet is opened. This is a safety device. Below are two fuses; the control switch for starting the motor; two other fuses, or heat-operated cut-outs, and terminals for the wires leading from this cabinet to the motor.

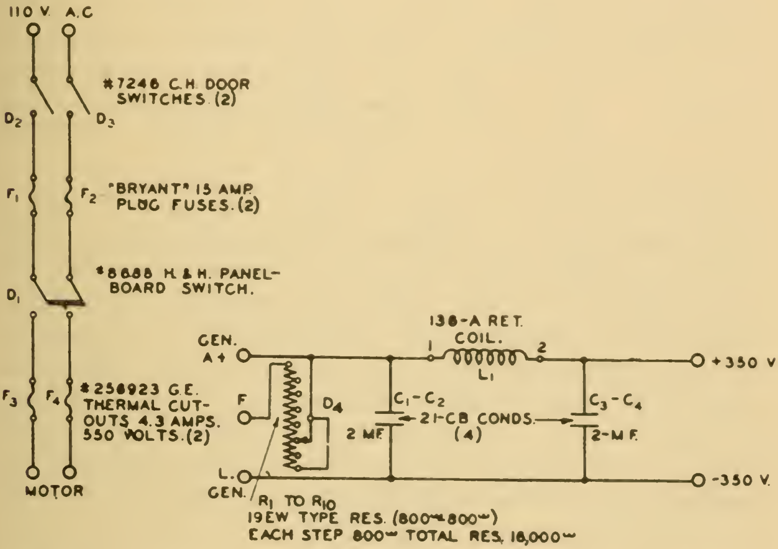

110 V. A.C
*7248 C.H. DOOR SWITCHES (2)
D_2
D_3
F_1
F_2
"BRYANT" 15 AMP. PLUG FUSES. (2)
*8688 H. & H. PANEL-BOARD SWITCH.
D_1
F_3
F_4
*258923 G.E. THERMAL CUT-OUTS 4.3 AMPS. 550 VOLTS. (2)
MOTOR
GEN. A+
F
L. GEN.
D_4
R_1 TO R_{10}
19EW TYPE RES. (800~800~)
EACH STEP 800~ TOTAL RES. 18,000~
138-A RET. COIL.
1
2
L_1
C_1-C_2
2 MF.
21-CB CONDS. (4)
C_3-C_4
2-M F.
+350 V
-350 V.

FIG. 176.—Schematic or simplified presentation of the circuits of Figure 112.

The second circuit shown is that of the generator. At the left are three terminals to which wires from the generator are connected. The central terminal, marked F, is wired to the generator field. Just to the right of this terminal is the generator field control (voltage regulating) rheostat, and to the right of this is the filter, consisting of retard coil L-1, and two sets of condensers (C-1, C-2, C-3 and C-4) in a conventional filter circuit. To the right of the filter are the two terminals through which the 350-volt direct current output is wired to the amplifier in which it is needed.

(9) In this drawing the electrical facts are arranged

with respect to the convenience of the eye and mind studying them. The electrical relationships of the different parts are shown as simply as the draftsman could draw them. But the actual physical apparatus must be arranged with respect to convenience in wiring and repair, and with regard to economy of space inside the cabinet that contains them.

Figure 175 shows the same equipment and wiring as Figure 176, drawn exactly as they are placed and wired in the physical cabinet. Every part shown in Figure 176 can be located in Figure 175 by reference to the part numbers. For example, the filter retard coil L-1 is shown at the lower left of Figure 175, just above the field rheostat terminal F.

Just above L-1, in Figure 175, is a complicated-seeming arrangement of resistors and a tap-switch, which would be troublesome to trace in detail if Figure 176 did not explain to us exactly what that resistance is, and precisely how it is wired into the circuit. It is, of course, D-4, the generator field control, or voltage regulator. There will never be the least occasion to trace its wiring in detail except in case of trouble within that resistor itself, or in its tap-switch contacts. Everything else the projectionist will ever need to know about it is most conveniently shown in Figure 176.

Rectifiers

(10) The almost universal practice today is to supply the voltage and current requirements of a sound system by means of step-down transformers where a.c. can be used (as in the case of the heaters of vacuum tubes), and by means of rectifiers where d.c. is essential. The rectifier is usually wired to the output of a transformer, which steps the a.c. voltage up or down, according to the d.c. voltage required. The rectifier (almost always a tube or pair of tubes) then converts the a.c. output of the transformer to d.c. of corresponding voltage. This d.c. is then filtered by condensers and resistors, or condensers and choke coils, to remove the small a.c. left

in the rectifier output. The entire combination of transformer, rectifying tubes and filter is sometimes referred to merely as a "rectifier."

(11) Rectifiers are diagrammed on pages 112 and 114, and their circuits and operation described in the accompanying text. Both of the rectifiers shown on those pages, however, derive their power from step-down transformers, and thus deliver low-voltage d.c. A rectifier that delivers high voltage d.c. for the plates of amplifying tubes is illustrated, and its action traced in detail, in the next chapter.

CARE OF TUBE RECTIFIERS

Sound supply rectifiers of the types just referred to require very little attention. (12) The relay contacts of S-1 and S-2, Fig. 51, page 114, should be burnished occasionally to insure that they make firm and solid connection.

Excessive heating of any part should of course be investigated immediately. Such over-heating may be caused by excessive current drain that must be corrected. It may be caused by a growing defect inside the coil or condenser in question, in which event a duplicate part must be procured at once. It may also be caused by a defective connection to the part, which should be resoldered. The cause need not be at the point where the overheating occurs, but can be a defectively low resistance in any other portion of the same circuit.

(13) In the event of any coil or condenser of the filter system burning out, when no spare is available for immediate replacement, a satisfactory temporary repair can usually be effected by borrowing storage batteries from the nearest charging station and connecting them in parallel to the damaged circuit. A sufficient number of cells should be connected in series to make the voltage of the battery as a whole equal to the voltage of the d. c. line in question. A storage battery "floating" across a d.c. line constitutes one of the best of all filters for slight to medium ripple.

(14) The tubes of this type of rectifier require some

attention. If either one burns out, that event will be indicated by a marked drop in the power supplied, as well as by a strong hum in the sound; the latter resulting from the fact that the unit is then operating on one tube only, as a half-wave rectifier, with a correspondingly heavier ripple which the filter is not designed to remove.

Hum will also be heard if one tube, through age or for any other reason, becomes much less efficient than its partner. In that case the good tube is carrying the greater part of the load, and the unit functions essentially as a half-wave rectifier. The defective tube must be replaced. In practice, two new tubes are installed, and the old ones tested by restoring them one at a time later on, when no audience is present.

(15) A short-circuited filter coil will cause hum; so will an open-circuited filter condenser. A short-circuited filter condenser will burn out the fuses F-1 and F-2, shown in Figure 51, alongside the tubes.

Mercury-Vapor Rectifier Tube

(16) A gas-filled tube is capable of rectifying heavier current than a vacuum tube of the same size. The gas commonly used for this purpose is mercury vapor. When the tube is cold drops of mercury can be seen clinging to the inner surface of the glass. The liquid metal vaporizes or boils when the filament is heated.

The action of the vapor is approximately as follows: electrons from the heated filament "collide" with atoms of the gas, thus ionizing them. In greater detail, what happens is that occasionally one of the outermost electrons of a mercury atom will find itself powerfully repelled by the field of an emitted electron, which is approaching rapidly from the direction of the filament. Under some circumstances the repulsive force acting on an atomic electron will be strong enough to drive it away from its atom. The remainder of the atom then constitutes a positive ion, while the detached electron goes on to the positive plate precisely as if it had been emitted by the filament. Therefore at any given moment during its operation a mercurcy-vapor tube contains numbers of positive ions of mercury, which assist the emission from the filament, in the following manner:

It must be remembered (see Page 93) that an emitting cathode is surrounded by a space charge. When the cathode is in the same tube with a positive plate, some of the electrons that make up the space charge are drawn to the plate. Some electrons, however, are emitted with such feeble velocity that they never travel far enough from the cathode to respond to the attraction of the distant plate, but return to the cathode instead. Thus the filament of a rectifying tube is surrounded by a thin layer of electrons. The presence of this layer, or space charge, exercises a repulsive force upon other electrons that are just inside the surface of the filament, and would be emitted if this surrounding space charge did not repel them.

But the positive mercury ions are attracted toward the space charge, which of course is negative, and unite with its electrons. The mercury ions then become neutral mercury atoms again until they are re-ionized by a new collision, and the space charge has been destroyed. Therefore the effect of mercury vapor in a rectifying tube is to make possible much greater emission than could possibly take place in a vacuum rectifier of the same size, with the result that a small mercury-vapor tube can, as before said, rectify as much current as a large vacuum tube.

"Dry Chemical Stack"–or "Disc"–Rectifiers

Tubes of either vacuum or mercury-vapor type can be omitted entirely, and the same work be performed by rectifying "stacks" or discs. Some circuit changes, however, would be needed if stacks were substituted for the tubes in Figure 51. The nature, operation and circuits of disc rectifiers are described on Pages 116-123.

SOURCES OF SOUND CURRENT

Practical Questions

(For answer to each question see corresponding number in text of Chapter XX)

1. From what three sources are sound currents obtained in the projection room?
2. Explain the action of a "lens tube."
3. What illumination does the photocell receive?
4. What does the photo-cell "see?"
5. How does the photo-cell "see" frequency?
6. What light-beam focus is necessary to reproduce 9,000 cycle sound? Why?
7. How does the photo-cell "see" volume?
8. How is volume recorded on a variable density sound track?
9. How is volume recorded on a variable area sound track?
10. Explain push-pull reproduction.
11. Does the use of push-pull recordings require any changes in the projection room?
12. Describe the construction of a photo-electric cell.
13. What is the difference between the cathode of a photo-electric cell and the cathode of a rectifying tube?
14. Describe the cathode of a photo-electric cell.
15. Describe the anode of a photo-electric cell.
16. How and why does the photo-electric cell create sound currents?
17. Are modern photoelectric cells vacuum or gas-filled cells? Why?
18. Describe and explain two methods of photo-cell coupling.
19. What is "condenser coupling"? "Transformer coupling"?

CARE OF SOUND-ON-FILM EQUIPMENT, PAGE 470

20. How is the exciting light focus adjusted?
21. Describe two practical methods of testing exciting light focus.
22. What harm is caused by oil in a lens tube?
23. What care does the sound gate or drum require?

24. What is "flutter"? Name two causes of flutter.
25. What harm is done by mis-adjustment of lateral film guides?
26. State two methods of testing the adjustment of lateral film guides.
27. What harm is done by vibration of any part of the light system?
28. What test is applied to discover vibrating parts of the light system?
29. What may be the basic cause for vibration of parts of the light system? What cure may be necessary?

REPRODUCTION OF SOUND FROM DISCS, PAGE 473

30. Describe the magnetic disc reproducer, and its action.
31. What are "hill and dale" records?

MICROPHONES, PAGE 475

32. Describe the common carbon-type microphone, and its action.
33. Explain "packing" in the carbon microphone, its causes and cure.
34. Describe three methods of coupling the sound pick-up to the system amplifier.
35. Trace the circuits of a combination fader-changeover-volume control.
36. Describe a common method of connecting non-synchronous sound currents to the system amplifier.

CHAPTER XX

SOURCES OF SOUND CURRENT

(1) The alternating (or pulsating direct) current that represents sound in the projection room is obtained from one of three sources:

(a) The film reproducing system, which contains a photo-cell circuit.

(b) The disc or phonograph reproducer.

(c) The announcing microphone.

The Sound-on-Film Pickup System

The photo-electric cell can deliver "speech current" only with the help of two other components. These are, the moving sound track, and the source of light by which the photo-cell is excited.

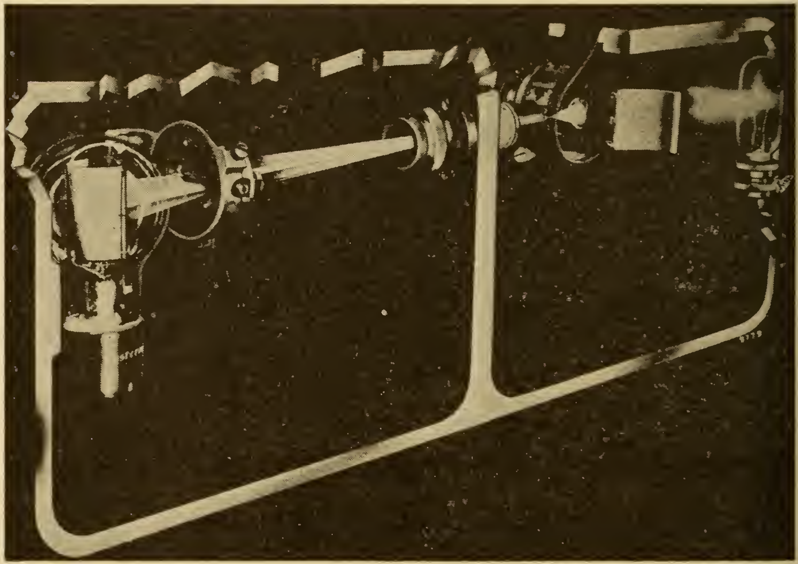


Fig. 177—Identical with Fig. 182.

The physical and optical arrangements between photocell, film and light source must meet definite requirements. The light must reach the cell *only* by passing through the transparent portions of the track, and by no other path whatever. Further, the light reaching the cell must be that which has passed through only one small portion of the track; that is, through a vertical portion represented by the finest striation, or by the smallest point, in Figs. 166 and 166 C. The reason for this latter requirement is given in detail later on; here we are concerned with the optical methods used to meet it.

Some of the more popular optical arrangements are shown in Figs. 177, 178. In Fig. 178 the exciting lamp is drawn at the left. The "lens tube" just right of the lamp contains a "slit"—a horizontal opening between two accurately machined knife edges. The height of this slit is different in different models of lens tubes, but may be taken as roughly 1/1,000″. (2) The exciting light is concentrated on this slit, and then focussed again on the film, located to the right of the lens tube. (3) The photocell, extreme right, receives only such illumination as the transparent portions of the sound track permit to pass.

The spacing of these slit edges is extremely critical since that spacing governs the highest frequency of sound that can be reproduced, regardless of what may be on the track. Thus poor quality in the sense of inadequate high frequency reproduction is sometimes traceable to slippage of one of the slit edges as a result of projector vibration, whereby the slit becomes very slightly wider. Noise in the sound may often be traced to minute loosening of the screws or other means used to mount the slit edges, permitting those edges to vibrate infinitesimally under the impact of the projector vibration. In that case the amount of light reaching the cell is altered at the same vibratory rate per second, and a noise of corresponding frequency is heard.

In Fig. 177 the exciting lamp is at the extreme right. A condenser lens, not visible in the drawing, concentrates the light on a restricted portion of the sound track. The light passing through the film is focussed on the photo-cell (extreme left) by an objective lens assembly. In this case the slit is not inside the lens assembly, but is externally mounted just right of the cell, and since the light beam is wider at that point, the spacing of the knife-edges is much greater than 1/1,000th inch, and far less critical. The arrangement of Fig. 177 is shown in further detail in Fig. 182.

Some optical systems use no slit, relying on a cylindrical condenser lens.

WHAT THE PHOTO-CELL SEES

(4) Assume that an opaque portion of the sound track cuts off the exciting light from the photo-cell, and is followed, a moment later, as the film moves downward, by a transparent portion. (See Fig. 166-166E.) Assume that opaque and transparent portions of the sound track replace each other in the path of the exciting light a thousand times a second, as the film moves downward. In that case the photo-cell sees a light turned on and off a thousand times a second. A human eye would not see that. A human eye would be deceived by the phenomenon of "persistence of vision," which makes moving pictures possible, into seeing a steadily-burning light of medium intensity. But the photo-cell can see a light turned on and off a great many times a second. When it sees this happen, for example, a thosand times a

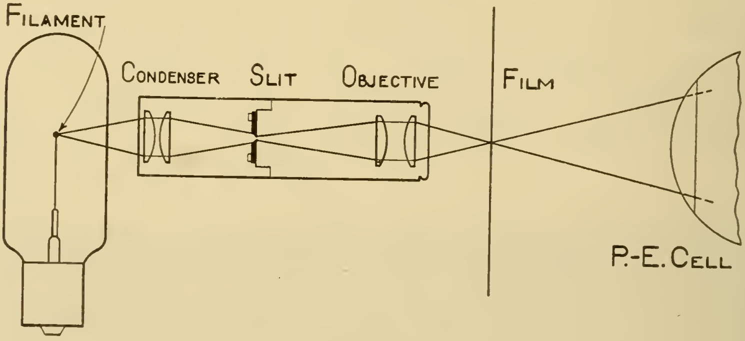


FIGURE 178

second, it responds (for reasons made plain below) by creating a thousand-cycle pulsation in the direct current flowing through it. If the opaque and transparent portions of the sound track are more crowded, and succeed each other five thousand times a second, the photo-cell creates a 5,000-cycle ripple in its direct current, etc.

How the Photo-Cell "Sees" Frequency

(5) Consider a high-pitched sound, say of 9,000 cycles (which is 18,000 alternations), photographed on a sound track. The photo-cell must see 9,000 transparent areas and 9,000 dark areas in one second's time if it is to create a 9,000-cycle pulsation in its direct current. The film moves downward at a uniform rate of 18 inches per second. Therefore if 18,000 different areas (9,000 light and 9,000 dark) are to pass through the sound gate in one second's time, each of these light and dark areas must occupy exactly one one-thousandth of an inch along the length of the film. (6) Now if the dark areas are to cut off the light completely, and the transparent areas are to transmit it completely, then the light beam itself must obviously be not more than one one-thousandth of an inch in height. But Fig. 177 shows an alternative method.

If 4,500-cycle sound were to be considered satisfactory as the upper limit of reproduction, then the light beam would need to be focussed to only 1/500th of an inch. But in every case the light must be brought down to some definitely narrow line at the point where it crosses the sound track. If this is not done at all, if a flood of light, say, an inch high, is permitted to pass through the film to the photo-cell, then it is plain that nothing higher than 18-cycle sound can be reproduced.

The function, therefore, of the slit assembly diagrammed in Figure 178 is to reduce the height of the beam to the dimensions necessary. In Fig. 177 excess beam height is masked and does not reach the cell.

The exciting lamp, which co-operates in this work, is unusual in that its filament appears as straight, horizontal line of wire. The light from this straight line of incandescence passes through the condenser lenses of Figure

178 to the slit. The objective lens focusses an image of the slit upon the film.

How the Photo-Cell "Sees" Volume

(7) Let us consider two musical notes that are identical in frequency, but differ in volume. Then in each case the photo-cell will see the same number of changes of light per second. But there will be a more drastic change in the case of the louder note, in consequence of which the cell will create a stronger ripple in the direct current flowing through it. The explanation of this cell action will follow in a moment.

(8) Here reference should first be made to Figure 166. This shows that in the "variable density" type of sound track the dark areas are darker, and the light areas lighter, in some portions of the sound track than in others. Those parts of the track in which the contrast between light and dark is greatest are the parts in which loud sound has been recorded—that is, those parts in which the action of the light valve in the recording studio has been strongest. Those parts of the variable density track where the light valve moved very little, and the contrast between light and dark areas is not great, represent low volume.

(9) With a track of the "variable area" type (Figure 166C) the amount of light reaching the photo-cell is varied by altering the areas of the light and dark portions of the track.

Push-pull Reproduction

(10) Reproducing the tracks of Figs. 167-A-B, etc., requires what is essentially a double photo-cell in a single glass envelope. Each of the twin cells receives light through one track only, the light beam being divided by some convenient means. In Figs. 177 and 182 a septum or mask divides the slit vertically. In other sound heads a double prism effects the division. The two photo-cell currents are electrically combined. One method of doing this is by the equivalent of Fig. 184. (11) Switching that wiring to parallel input or the equivalent of Fig. 180,

and eliminating the division of the light beam, enables the same equipment to reproduce the tracks of Figs. 166-A-B-C, etc. Switching is needed because either type track would be cancelled electrically by the wrong type of output circuit.

CONSTRUCTION OF PHOTO-ELECTRIC CELL

(12) The principle of construction in the photo-cell is very simliar to that followed in the rectifying tube. In each case there is a cathode and an anode. (13) The difference is that the cathode of the photo-cell is not a filament serving as an emitter when it is heated, but a light-sensitive metal serving as an emitter when it is illuminated. When light is shut off emission ceases. The response is instantaneous. When light is admitted to the cathode the emission varies in strength in proportion to light intensity.

(14) Because it operates by light rather than heat, the cathode of the photo-cell is not a thin filament wire, but a broad surface for maximum interception of light. It takes the form of a film or layer of the active metal deposited on the inside of a curved element provided for that purpose. (15) The anode or "plate" of the photo-cell is not a plate at all, but a thin bar or thin ring of metal that will shadow the cathode as little as possible.

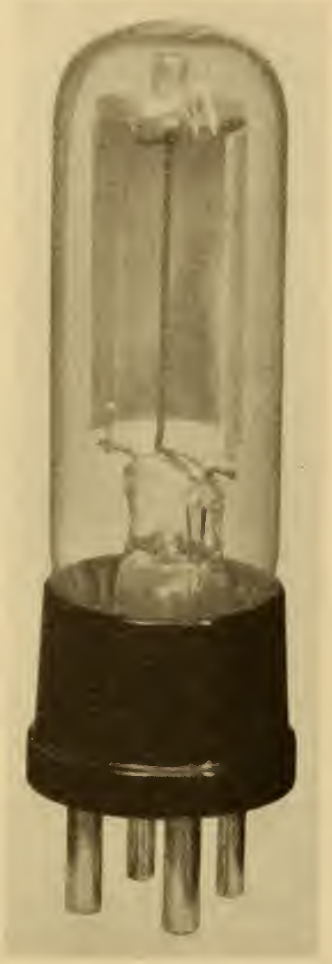


FIG. 179.—A modern type photo-electric cell.

The two elements of the photo-cell are connected across a source of extremely steady, ripple-less direct current, drawn, in modern sound equipment, from an exceptionally well-filtered rectifier supply. One such circuit is shown in Figure 180. (16) Electrons emitted by the cathode when light strikes it are attracted to the positive anode. This action constitutes a flow of current across the cell. Because the emission depends entirely upon the light reaching the cathode, the cell acts as a highly sensitive valve, permitting current to flow through it (anode voltage being constant) in proportion to the amount of light to which it is exposed. Since the response of the cathode is substantially instantaneous, the cell finds no difficulty in dealing with light fluctuations that correspond to even the highest frequencies of audible sound.

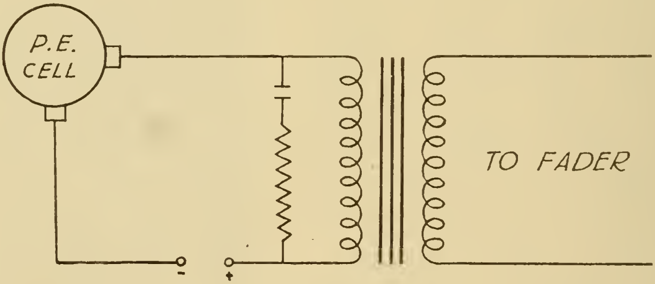


Fig. 180.—Photo-cell coupling. (Transformer coupling).

The arrangement of Figure 180 results in a flow of pulsating direct current through the primary winding of the coupling transformer. The amperage flowing (the micro-amperage, to be more exact) will fluctuate in strength as many times per second as the light entering the cell changes, and will be proportionate in its strength to the strength of that light.

Thus the opaque and transparent areas of the sound track are converted, through the motion of the film and the operation of the photo-electric cell, into corresponding pulsations of direct current.

VARIETIES OF PHOTO-CELLS

(17) Modern photo-electric cells are gas-filled because the presence of gas increases the emission of such cells in precisely the same way that gas increases the emission of a rectifier tube filament. (See Page 93.) The gas used in photo-cells, however, is not mercury vapor, but one of the rare gases, usually argon.

PHOTO-ELECTRIC CELL COUPLING

(18) Figure 180 shows one possible method of "coupling"—that is, wiring—the photo-electric cell to the switches, volume controls and amplifiers in which the pulsations of its direct current are controlled and amplified. In Figure 180 that current merely flows through the primary of a step-down transformer. The result is a flow of alternating current in the secondary winding that reproduces all the fluctuations of the pulsating direct current in the primary. But the voltage and amperage may be altered, according to number of turns in the primary and secondary coils. The sound current drawn from secondary of the transformer in Figure 180 passes through a fader before entering the system amplifier. The fader is essentially a double-throw, double-pole switch that connects the system amplifier with sound current from either projector. In some systems the fader serves as a volume control as well as a changeover. In such cases it is not built in the form of a switch, but of a double potentiometer, as explained in connection with Fig. 185.

A second method of photo-cell coupling is shown in Figure 181. This method is used in connection with an amplifier mounted on or near the projector, and connected to the photo-cell by a very short wire. It deserves exceptionally careful study because the identical circuit is also used in amplifiers for "coupling," or wiring together, amplifying tubes.

In Figure 181 electrons from the d.c. source travel to the cathode of the cell, are emitted under the influence of light, and cross the cell to the anode. Thence they move through Resistor A to the positive side of the d. c. source, thereby completing their circuit.

But a parallel circuit can be traced from the d. c. negative terminal through the common ground, thence upward through Resistor B, then through the condenser and downward through Resistor A to the positive d. c. terminal. Since this circuit contains a condenser in series with it, it cannot carry smooth d. c. but only the ripple, or a. c. component, created by the photo-cell action.

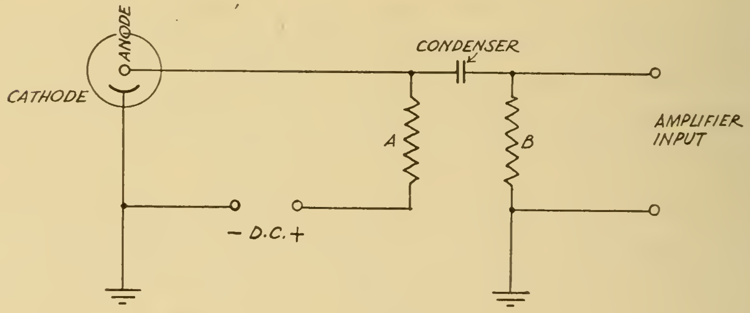


FIG. 181.—Photo-cell coupling. (Condenser-resistance coupling.)

This ripple or a.c. component of the current is precisely the part that corresponds to the sound to be reproduced, and by the circuit of Figure 181 it has now been transferred to Resistor B, which looks into the amplifier. The alternating voltage drop across Resistor B is wired directly to the input terminals of the amplifier.

(19) This arrangement is condenser-resistor coupling. The arrangement of Figure 180 is called transformer coupling. Either may be used in connection with photo-electric cells, or between the tubes of amplifiers.

CONTROL OF FILM MOTION

In many sound heads, the film is held by a "gate" at the point where exciting light passes through the track, but the most modern design replaces the gate with a rotating drum. The drum has no gears; it is driven by the film itself. Its motion is stabilized by a flywheel coupled to the drum shaft only through a film of oil. The drum consequently possesses remarkable steadiness of rotation which in turn controls the film motion at the vital point for good sound, eliminating irregularities that would otherwise be heard as "flutter" or "wows." The arrangement is known as a "rotary stabilizer" or "kinetic scanner." See chapter on *Drives.*

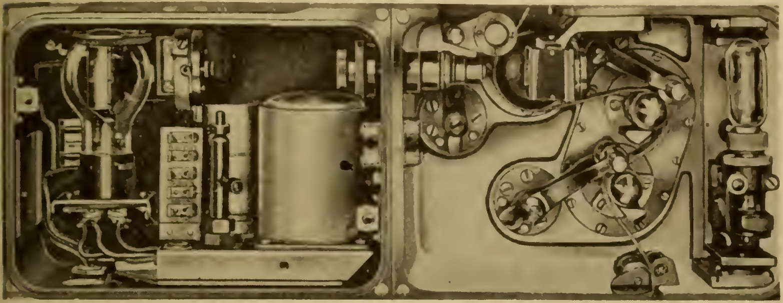


Fig. 182.—Mirrophonic Soundhead. Identical with Fig. 177.

In most sound heads, the film is moved by sprockets geared to the drive motor. Fig. 183 is an exception; the film is looped back from the sound head to the lower projector sprocket, and thence downward again to the lower magazine. Since the film in this case is taken directly from the intermittent sprocket, it might seem that the pulsations of the projector's lower loop must be heard in the sound as flutter, but actually this is not the case. The rotating drum of the kinetic scanner, just referred to, keeps the film moving steadily at the point where it passes the exciting light. This head has been widely used and in practical operation has shown no marked tendency toward flutter.

The kinetic scanner drum, as explained under *Drives,* is driven by the film itself, and since there are no sprockets in Fig. 183, the soundhead there shown needs no connection of any kind with the driving motor. The motor is coupled only to the projector and to the lower magazine take-up, exactly as if no soundhead were installed.

Care of the Film Reproducing System

Everything about the film reproducing system is delicate, and requires extreme care. The focus of the exciting lamp is a matter of a fraction of a thousandth of an inch. The current of the photo-electric cell is a matter of a millionth of an ampere. And the slightest defect or irregularity in this part of the apparatus is subject to the full amplifying power of the sound system.

The soundhead generally needs more attention than any other part of the sound installation, sometimes more than all other parts combined. Nowhere else in the system are mere physical tolerances and clearances both as critical and as easily deranged in the course of ordinary operation. Nowhere else is dirt introduced, not by accidental seepage but by introduction of a foreign material carrying dirt (the film). Some troubles (flutter for example) cannot occur anywhere except in the soundhead, while any trouble that occurs there, such as hum or distortion, is subjected as said to the maximum possible amplification. The film reproduction system needs watching all the time.

(20) The focus of the exciting lamp must be accurate. In the normal course of operation correct focus is secured either by adjusting the lens assembly or by careful placing of the exciting lamp, or both, depending on the design of the sound head, details of which vary. (21) With many heads, a rough test for focus is to hold a white card in front of the photo-cell and adjust the focus until a clear white oval is obtained. But a very much more accurate test is to run a loop of high-frequency test film, six or nine thousand cycles, while an output meter is connected in the loud speaker circuit. The output meter reads sound volume in decibels (the decibel is a unit for measuring volume as the ampere is a unit for measuring current). The exciting lamp mounting is then adjusted until the maximum volume is shown by the registration of the meter.

All lenses and prism surfaces must be kept clean and free from oil. The outer lenses are cleaned with tissue paper, preferably lens tissue. In some makes of equipment the lens tube can be opened, cleaned and adjusted

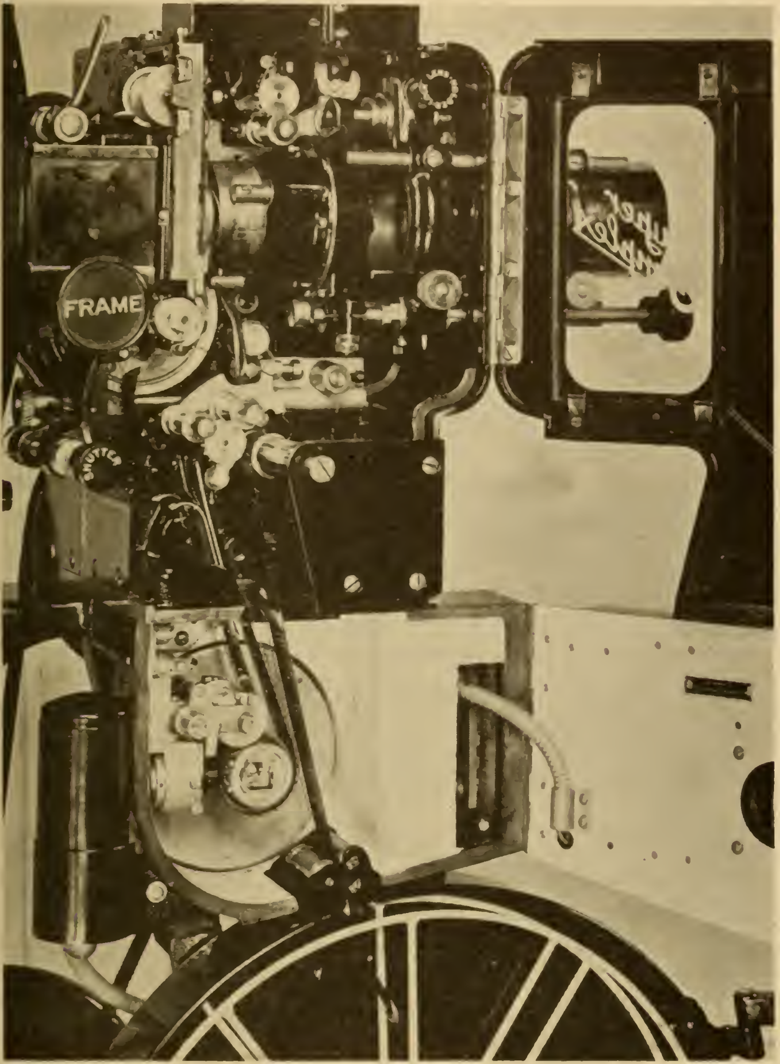


Fig. 183.—The exciter lamp is in the chimney-like structure at the left. The light passes through a lens tube, thence through the sound track, which protrudes beyond the edge of the scanning drum. Within the drum circumference is a prism that deflects the light at right angles to where the door would be if the door were closed. The photo-cell can be seen inside the door structure.

in the projection room, but other manufacturers seal their lens assemblies to prevent this practice. Some types of assembly can be focussed in the projection room, while in others the focus is fixed and the exciting lamp controls are the only means of modifying the focus.

(22) Oil should be kept away from lens tubes. It may seep inside, vaporize under the heat of the exciting lamp, and turn the light yellow. The photo-electric cell does not respond well to yellow light. Loss of volume, especially at high frequencies, is experienced when the exciting light is dimmed in this way, and the only remedy is either to open and clean the lens assembly (if it can be opened in the projection room) or to return the assembly to the factory for overhauling.

(23) The sound gate, pad, or drum, must be scrupulously clean. Particles of lint or film wax or other foreign matter may vibrate with the motion of the film and add an unintended interruption to the light. This will result in noisy sound.

(24) The motion of the film past the sound gate must be utterly smooth. The slightest jerk will result in "flutter," which is a tremolo in the sound, and very unpleasant. The same result will follow if the film is not held in its proper position, but permitted to move forward and back through the point of focus. The motion of the film is controlled by the sprockets and idlers, or drums, described in detail on another page under the heading of "Drives."

The "lateral guides" control the film on its downward course to insure that the entire sound track, and nothing but the sound track, passes through the exciting light. (25) There are sprocket holes in the film on one side of the sound track, and dividing lines between the pictures on the other side. If the film is laterally displaced so that either pass through the light beam, the light will be interrupted at the frequency with which sprocket holes (or dividing lines, as the case may be) pass through the point of focus. A loud hum or "motor-boating" in the sound will result. (26) This can be cured by adjusting the lateral guides until it is no longer heard. An observer in the theatre is necessary if the adjustment is to be made with the greatest accuracy, since a slight trace of such noise will not be heard by the projectionist above the noise of his machinery, although loud enough to annoy the audience.

A very perfect adjustment of the lateral guides is made by threading a piece of blank leader in the projector and photographing the exciting light upon it. An exposure of from 30 seconds to one minute will leave a thin black line on the blank film. The drive should then be turned to move the film about six inches, and another exposure made. Four or five such exposures will reveal very accurately whether the film is out of adjustment laterally with respect to the exciting light. After the guides have been re-set the light must be photographed again, and so on, until a perfect setting is obtained and the guides are locked into place.

(27) It is necessary to guard against the slightest vibration of any part of the light system. If the optical slit vibrates, or if the filament of the exciting lamp vibrates, the resulting vibration of the light beam will be heard in the sound as noise. (28) The exciting lamp and its holder should be tested for vibration by tapping them gently with the back of lead pencil, one that has no eraser. The lens tube may be rapped more vigorously with the same instrument, or tapped very gently with the butt of a screw-driver. The photo-electric cell and its amplifying tubes, if any, should be tapped softly with the side of a pencil. Any noise heard in the sound as a result of these tests means that the part in question is subject to vibration and must be tightened accordingly, or replaced. (29) The basic cause, however, may be excessive projector vibration requiring an extensive overhaul.

THE DISC REPRODUCER

The disc or phonograph reproducer of electrical type uses its vibrating needle (see page 427) to create speech currents identical with those produced by a photo-cell, but at somewhat higher volume. Two general types of reproducers are used in theatres today: the magnetic type, and the crystal.

(30) The phonograph pick-up, or reproducer, is a miniature generator in which the physical motion that generates current is reciprocating, rather than rotary as in the case of a power-supply generator. The needle tracking the groove of the record vibrates from side to side at the same frequency with which irregularities of the groove follow each other. The distance through which the needle vibrates varies according to whether the irregularities of the groove are large or small.

Attached to the needle, inside the reproducer, is a small piece of iron. Lines of magnetic force originating in a steel magnet within the reproducer flow through this piece of iron and also through a coil of wire. When the needle vibrates, the piece of iron attached to the needle holder vibrates with it, and the strength of the magnetic field, as it passes through the coil of wire, is varied accordingly. This change in magnetic strength generates an alternating current in the wire. The frequency of this current corresponds to the frequency of the needle's vibration, and its strength to the distance through which the needle moves.

Some of the highest grade pick-ups contain oil as a "damping" medium. The needle-holder assembly is generally resonant at some frequency of audible sound, and will therefore tend to vibrate more strongly at that frequency than at any other. The oil counteracts this tendency, but makes projection room repair of the pick-up distinctly difficult. It is not easy to replace the oil even if the right oil is at hand, and for that reason it is good practice to return such pick-ups to the factory even for simple repairs, rather than open them in the theatre.

The disc reproducer needs comparatively little attention, but the record and its turntable, and the reproducer mounting, or tone-arm, are almost as delicate in their requirements as the photo-electric cell equipment. Both turntable and tone-arm must be perfectly level, or the needle is likely to leave one groove and jump (fall downward) into another. A spirit level is used to check them from time to time. The record must turn smoothly, without any jerkiness in its motion, or flutter will result.

The needle point must be sharp enough to track through those slight variations of the groove that represent the highest frequencies of sound engraved on the record.

"Crystal" pick-ups are also popular in modern theatre installations. They do not contain a magnet and a coil of wire, but a thin crystal of rochelle salts. A crystal of that salt will, for reasons unknown, generate current when it is subjected to a twisting motion. The needle and needle-holders are arranged to impart such a motion to the crystal in response to the irregularities in the groove of a moving record.

(31) "Hill and dale" records are those in which the groove is cut deeper and shallower, instead of wavering from side to side. In the common, or lateral-cut records, the spacing between grooves limits the amount of wavering possible, and therefore the volume. There is no such limit in the hill and dale. Hill and dale reproducers of course differ in construction from lateral-cut reproducers, in that the needle vibration must be up-and-down instead of from side to side.

Sound-on-disc can be obtained from any phonograph equipped with an electrical reproducer. It is widely used for exit marches and incidental music. The type of electrical reproducer must be such that its output impedance matches the input impedance of the "disc" input circuit of the amplifier. If the "disc" input of the amplifier is of low impedance a crystal reproducer is unsuited. If the amplifier "disc" input is of high impedance, the low impedance type of magnetic reproducer is unsuited.

MICROPHONES: CARBON, CRYSTAL, DYNAMIC, VELOCITY

(32) The common, or carbon-type, microphone consists of a carefully weighed quantity of carbon granules between two metal plates, one of which is a diaphragm

free to vibrate in response to sound vibrations in the neighboring air. The effect of the vibration is to vary the pressure on the carbon and thereby change its resistance to the flow of current. A steady direct current passes through the microphone. When the diaphragm vibrates the amperage increases and decreases in rhythm with the frequency of the sound that causes the vibration, and in proportion to its intensity. The commonest microphone circuit is that for the "double-button mike," shown in Figure 184. The granules in one "button" are compressed while those in the other are released from pressure. The resulting fluctuations in the current through the transformer primary generate an alternating current of corresponding frequency and strength in the secondary.

(33) The carbon granules of this microphone may "pack" or cling together as a result of rough handling or of age. In that case they will not respond to vibration of the diaphragm. Gentle shaking will sometimes cure this condition. In severe cases it is incurable in the theatre.

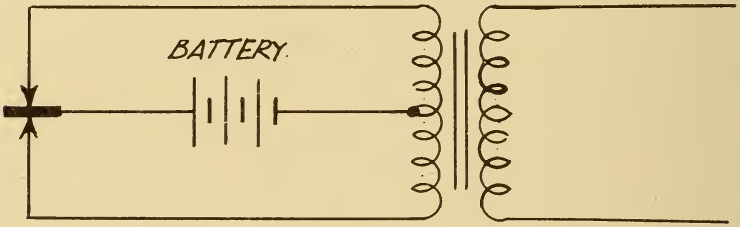


FIG. 184.—Circuit of a double-button carbon microphone.

Packing can be detected by reading the current through both buttons with a milliammeter, and this test should be applied from time to time as a precaution. Both buttons should have the same resistance, and if there is a marked difference in the meter readings the granules in one of the buttons are probably packed.

Excessive current through a carbon microphone will pack and ruin it. Minute sparking between the carbon granules will weld them together so firmly that only new carbon will restore the instrument.

The crystal microphone can conveniently be thought of as a close relation to the crystal type phonograph pickup. The rochelle salt in the pickup receives its vibratory impetus from the phonograph needle, while the microphone responds to similar vibrations in the air. Crystal microphones are manufactured in a number of types, broadly distinguished as "diaphragm" and "sound cell" models. In the former, sound waves operate against a diaphragm mounted in the microphone casing, and mechanically connected to the crystal in such a way as to impart the necessary twisting motion. In the latter, the crystals are acted upon directly. There is no diaphragm, but the method of mounting each "cell" of crystal is such that waves of air pressure twist the cell in the proper manner. The elimination of all mechanical parts reduces distortion, and a sound cell crystal microphone delivers sound of remarkable purity. Volume is increased by multiplying the number of cells, which in practice vary from two to twenty-four. The price of the microphone increases with the number of cells used.

Both types of crystal microphones are available in mountings or cases that facilitate directional response, the cases being so designed that they tend to intercept or block off sound originating in certain directions. The diaphragm type is also made for 360-degree response: the diaphragm lies horizontally across the top of the casing, and is depressed by passing waves of air pressure.

As the crystal microphone is like the *crystal* phonograph reproducer in principle of operation, so the dynamic microphone can be regarded as analogous to the *magnetic* type of phono pickup. Dynamic microphones are always equipped with diaphragms; details of their physical construction vary, but in every case vibration of the diaphragm results in vibration of a conductor located within a magnetic field. The conductor is consequently able to deliver speech current to the input circuits of an amplifier. Dynamic microphones usually have casings that are adjustable to give either directional or non-directional pickup, as desired.

The velocity microphone is electrically a special variety of the dynamic type. It has no diaphragm, or rather, the conductor that vibrates in the magnetic field is itself the diaphragm. It is not a wire, but a broad, ribbed ribbon of aluminum or aluminum alloy. The ribbon is inherently directional; sound waves approaching its narrow edge do not move it, but it responds to sound originating in front of or in back of it. The case may be equipped with adjustable elements that serve to modify the frequency response of the instrument—that is, its relative sensitivity to sounds of different frequencies.

There are also now available for theatre work combination microphones, in which both velocity and diaphragm-dynamic mechanisms are mounted in a single compact casing, and deliver their joint speech current to a single pair of output terminals.

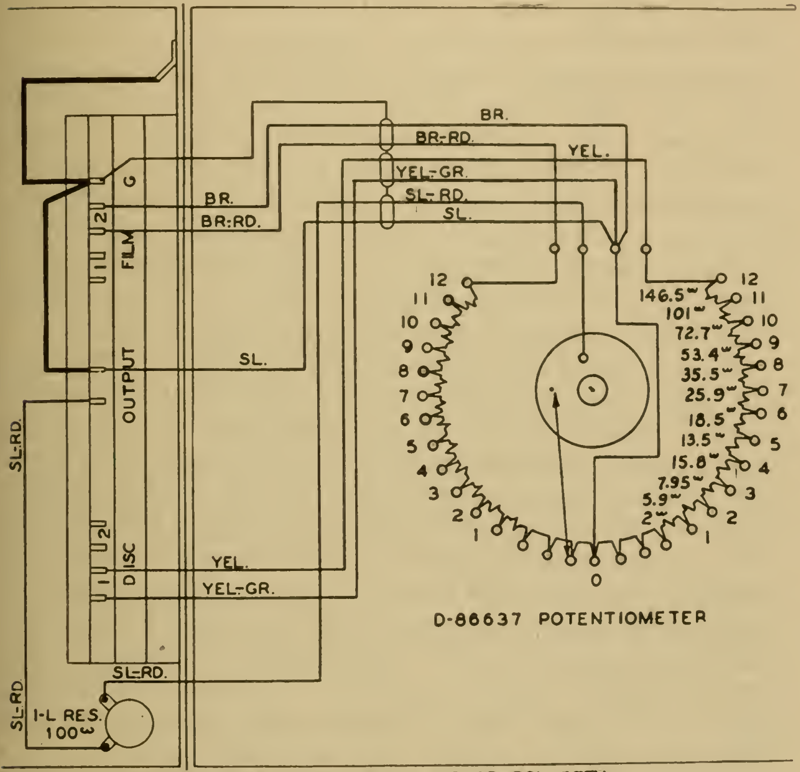
(34) There are almost as many methods of coupling sound pick-up to the system amplifier as there are types of sound equipment.

The simplest method is by use of a short cable from each photo-cell to the system amplifier. These cables run to a double-throw switch inside the amplifier casing. That switch serves as a fader, selecting sound from either projector, as desired. Volume is controlled by a potentiometer in one of the amplifier circuits.

When the photo-cell coupling system of Figure 180 is used, the length of wire between the transformer shown in that diagram and the system amplifier is of no importance. A fader or changeover may be built into the amplifier for use with this method of coupling, or may be mounted in a separate cabinet, the output leads from which are then wired to the amplifier. The volume control is a potentiometer in one of the amplifier circuits.

When the sound system includes a small photo-cell amplifier mounted on or near the projector (see Figure 186) the output from that amplifier to the main amplifier may run through a fader that is built as a double potentiometer and therefore serves as a volume control also. One device of that kind is diagramed in Figure 185.

(35) Figure 185 represents one of a number of essentially similar devices created to serve simultaneously as volume control and as changeover. The projectionist who takes the trouble to follow the circuits of this simple



VIEW LOOKING AT INSIDE OF BOX WITH TOP OF BOX OPEN.

FIGURE 185

diagram should have no trouble tracing out the wiring of any of its cousins.

Along the left-hand side of Figure 185 are eleven terminal contacts, drawn as small rectangles. The top terminal is labelled "G" and connects to the grounded casing. The four terminals immediately below "G" are marked "Film 1 and 2." The output leads from the film reproducing system of each projector are wired to these two sets of terminals. About an inch below these are two terminals marked "Output." Through these this change-over device connects with the main amplifier. Below these, again, are two pairs of terminals for the synchronous disc input.

Let us return to the top left of this drawing, to the film input from No. 2 projector. The upper wire of this pair is brown and may be traced to Point O of the potentiometer. The lower wire, brown-red, runs to point 12 of the left-hand side of the potentiometer. Thus half the resistance of the potentiometer is connected in parallel across the input from film reproducing system No. 2. Sound current coming from No. 2 projector, originating in its photocell, completes its circuit through the left-hand half of this potentiometer, and a corresponding alternating voltage drop exists across that resistance.

Now, looking at the two output terminals, we find that the upper peg, connected to the slate wire, also makes contact with Point O of the potentiometer, while the lower output terminal runs through the slate-red wire to the rotating element of the potentiometer, and its sliding contact. By means of this sliding contact (indicated by the double arrowhead which in the drawing connects the rotating element with Point O) any desired percentage of the voltage drop across the left-hand side of the potentiometer may be connected with the output terminals, and hence with the system amplifier. Volume from No. 2 projector is controlled by turning the central knob and thus changing the position of the sliding contact.

To change over, all that is necessary is to swing the central knob so that the sliding contact operates on the right-hand side of the potentiometer. Doing so disconnects the lower Output terminal from Projector No. 2, and places it in contact with Projector No. 1. The wiring from Film Terminals No. 1 to the right-hand side of the potentiometer is omitted from the drawing because it is an unnecessary complication. This wiring is identical with that connecting the left-hand side of the potentiometer to Terminal No. 2. Upper Terminal No. 1 runs to Point O; lower Terminal No. 1 runs to Point 12 of the right-hand half of the potentiometer.

The reader may care to trace out the Disc input connections of this circuit. No. 1 disc input wiring is shown; No. 2 disc input wiring is obviously the identical circuit applied to the opposite side of the potentiometer.

A number of control cabinet circuits similar to this one are equipped with supplementary key switches that do not alter the essential simplicity of the device, but add to the time required to trace out the drawings. One such switch may remove the potentiometer from the circuit entirely and substitute a resistance equal to that of a medium setting. This is for emergency, in case of trouble with the potentiometer resistors. Another such key is often provided to allow for the use of three projectors. This key is so wired that either No. 1 input or No. 2 input, as desired, may be used to take care of No. 3 projector. None of these circuits can be understood at a glance, but none of them will present any particular difficulty to any projectionist who is willing to take ten or fifteen minutes to trace their wiring step by step. Such analysis should, obviously, be made by every projectionist long before trouble occurs and compels him to attempt it under the pressure of an emergency.

Fig. 186 is a wall cabinet containing very different circuit arrangements, which will be traced in detail under the heading of Amplifiers. One of these cabinets is conveniently mounted in front of each projector. The electrical arrangements include a very compact two-stage photo-cell amplifier in each cabinet. These amplifiers are not "socket-powered" but derive their necessary power supplies from the system amplifier located elsewhere in the projection room. Each photo-cell amplifier incorporates a volume control, different from that of Fig. 185, in its amplifying circuits. In addition to their amplifiers, each cabinet contains a sound changeover switch. Switching circuits are so interlocked that changeover can be made from either cabinet at any time. A bullseye below the changeover switch shows at a glance which projector is delivering sound to the system.

SWITCHING AND NON-SYNCHRONOUS SOUND

(36) Such control cabinets as that shown in Figs. 185 and 186 are not used with non-synchronous sound. In theatres that use announcing microphones or non-synchronous phonographs the output of Fig. 185 or 186 would run to a small switching panel mounted with or near the main amplifier, not to that amplifier direct. By means of that switching panel the amplifier system can be connected either with the source of synchronous sound (output of Figs. 185-186) or with the non-sync source, as desired. The wiring of such switching panels is in the same class with that of Figure 185, in containing nothing but simple electrical circuits, very easy to trace by anyone who is willing to give the job just a little time and patience. These circuits, also, should always be studied long before trouble appears.

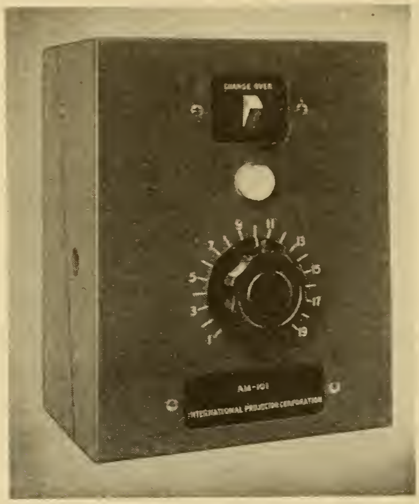


FIGURE 186

THEORY AND WIRING OF AMPLIFIERS

Practical Questions

(For answer to each question see statement of corresponding number in Chapter XXI)

THE AMPLIFYING TUBE, PAGE 485

1. What is most important part of every amplifier?
2. How does it differ in construction from the rectifying tube?
3. What is the "space current" of an amplifying tube?
4. What is the "plate current" of an amplifying tube?
5. What is amplification?

AMPLIFICATION AND ITS FUNDAMENTAL CIRCUITS, PAGE 487

6. How is amplification secured in the 3-element tube?
7. Draw a simple amplifying circuit. Explain its action in de-detail.
8. What is inter-tube coupling? Describe the two common types.
9. What are some of the commoner methods of coupling used in amplifiers?
10. What is a push-pull amplification?
11. Why is it used?
12. Draw a simple push-pull circuit. Explain its action.
13. What is "inter-electrode capacitance"?
14. What is "feed back"? "Reverse feed back?"
15. What is "oscillation"?
16. How can amplifying power per stage be increased?
17. Describe the construction and purpose of a 4-element, or screen grid, tube.
18. Describe the construction and purpose of a 5-element tube, or pentode.
19. Explain "triode" and "tetrode."
20. Distinguish between Class A and Classs B amplification.
21. Explain Class AB amplification.

Amplifier Power Supplies, page 509

22. What plate voltage supply do amplifiers require?
23. Name and describe four methods of providing plate voltage for amplifiers.
24. What filament power supply do amplifiers require?
25. Name and describe four methods of providing filament power for amplifiers.
26. What grid voltage supply do amplifiers require?
27. Explain six methods of providing amplifier grid voltage.

Care and Troubles of Amplifiers, page 516

28. Name three items of care required by amplifiers.
29. Explain three ways in which a tube can be "bad."
30. Give two causes of bad contacts in amplifiers.
31. What two kinds of trouble are caused by imperfect contacts?
32. What three kinds of trouble are caused by overheating in amplifiers?
33. What three conditions might cause hum in amplifiers?
34. How are amplifiers studied in practical projection room work?
35. What can be done if a schematic diagram is not available?
36. What is the function of the wiring diagram?

CHAPTER XXI

THEORY AND WIRING OF AMPLIFIERS

(1) Tubes are the heart of every amplifier; their construction and operation must be understood before the circuits of amplifiers can have any meaning.

Construction of a 3-Element Vacuum Tube

The three-element amplifying tube is composed partly of a cathode and an anode placed in a vacuum, and to that extent is in no way different from the rectifier tubes described on Pages 90-93. (2) The amplifier tube can be thought of most conveniently as a rectifier tube with one element added, namely, the grid, or, more accurately the control grid (since there are also four- and five-element amplifying tubes that contain additional grids of no importance to the present discussion. Such additional grids are explained on Page 95.) The commonest type of amplifying tube contains only cathode, anode and control grid. The control grid is placed between the cathode and the anode. Electrons emitted by the cathode, and moving toward the anode, must pass through the control grid to reach their objective. That is the essential point about the tube's construction.

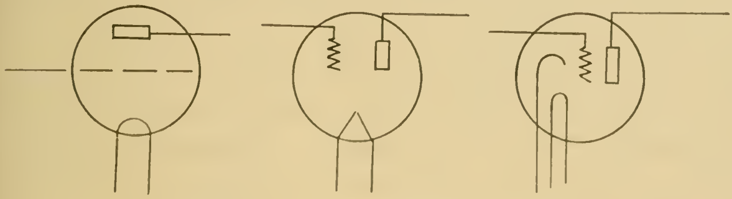


Fig. 187.—Three-electrode tube or triode

The Cathode of the Amplifier Tube

Cathodes in amplifier tubes are of two general types, direct and indirect heaters. The direct heater may be lit by either d. c. or a. c., if its temperature cannot change quickly enough to fluctuate with the a. c. cycle. If it is small, and quick to heat and cool, the cathode must be heated by d. c. Otherwise its emission will fluctuate at the line frequency (25, 50 or 60 cycles) and a corresponding hum will be heard in the sound. Indirect heaters have already been explained. (Page 91.) They make it possible to heat the cathodes of small tubes with a. c., without corresponding variation in emission. In such tubes the heating circuit and the cathode circuit are electrically insulated from each other.

Anode of the Amplifier Tube

The anode of an amplifier tube is commonly a flattened ring of metal, but in large tubes it is sometimes made of graphite or carbon. The choice of these latter materials arises from a desire to keep the anode as cool as possible. In large-size theatre tubes, metal anodes become heated, sometimes to the point of glowing red or even white-hot, because they are subjected to incessant bombardment by electrons emitted from the cathode. And an incandescent anode is in itself an emitter, like any other incandescent metal. And while electrons emitted from the anode are drawn back into it again by its powerful positive charge and do not take any direct part in the tube action, the cloud of electrons that have left its surface and not yet returned to it constitutes a space charge surrounding the anode which tends to repel electrons approaching from the cathode. Carbon or graphite anodes, being thick and massy, are not easily heated to the point of incandescence. A graphite-anode tube is therefore capable of somewhat greater current flow from cathode to anode (and hence of greater volume without distortion) than a metal-anode tube of the same size. There are other advantages, however, in favor of metal-plate tubes. Both types are widely used at the present day, but the latter are more common.

GRID OF THE AMPLIFIER TUBE

Placed between anode and cathode, the grid consists of a metal skeleton or mesh with plenty of empty space between the turns of the spiral. It may be a ladder-like construction of metal, with empty space between the wire "rungs." It may be a loosely-woven fabric of metal screen, or "cloth." Occasionally it consists of a metal plate in which many holes have been drilled. The object of its construction is to compel electrons moving through the tube from cathode to anode to pass close to the metal of the grid, without, however, interposing any physical barrier in their path.

"SPACE CURRENT" OF AN AMPLIFYING TUBE

(3) The flow of electrons from cathode to anode, across the empty vacuum of the tube, is called the "space current," (4) or plate current. If there were nothing else in the tube but the anode and cathode (no grid) the size of the plate current in milliamperes would depend wholly upon the emission from the cathode and the positive attraction of the anode.

(5) Amplification as obtained in a vacuum tube is the process of using a weak variable grid voltage to cause strong variations in the plate current. The tube, in short, is a valve, operated by a weak current and controlling a strong one. This has been said before. It cannot be repeated too often. When once that much about a tube is thoroughly understood it ceases to be any kind of mystery and becomes a very simple piece of electrical apparatus, with circuits that behave like any of the ordinary electrical circuits with which everyone is familiar.

HOW THE TUBE AMPLIFIES

(6) Consider first the plate circuit. It has two wires, like any other circuit. One of these wires connects to the cathode of the tube, one to the anode. The positive wire goes to the anode. When the cathode is heated electrons flow across the tube from cathode to anode, closing the

circuit. The strength of the current depends on the number of emitted electrons that reach the anode, and hence upon the voltage across the tube and upon the volume of the emission.

Next, consider the grid circuit. It has two wires, like any other. One wire goes to the cathode, one to the grid. Cathode and grid are a small condenser; that is, two conductors separated by the insulation of the vacuum. The grid is normally kept negative with respect to the cathode (how this is done is explained further on), hence emission cannot contact the grid and short-circuit the grid-cathode capacitance.

The grid circuit consists of two wires, its "load" is a tiny condenser; its source of voltage is the only unusual thing about it. There are two sources of voltage, connected in series. One is the source of sound voltage to be amplified. This may be the secondary of a transformer, as in Figure 189. The other is plain d.c., wired negative to grid and positive to cathode, and called the grid (or "C") bias; it keeps the condenser always charged with cathode positive and grid negative, while the sound source in series varies the strength of that charge as its own strength and frequency change. The essential electrical characteristics are diagrammed in Figure 188.

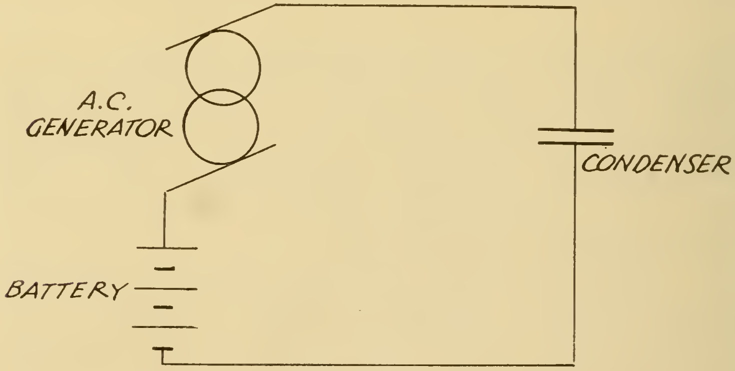


Fig. 188.—The electrical equivalent of a grid circuit

These two circuits, grid circuit and plate circuit, are then simple electrical arrangements with nothing mysterious about them. The grid circuit arrangements are unusual, but not puzzling. The valve action of the tube depends upon the fact that the plate current (the flow of electrons from cathode to anode) is extremely sensitive to the degree of negative charge upon the grid.

The reason for this sensitivity lies in the construction of the tube, which is so made that electrons moving from cathode to anode must pass close to the metal of the grid. They do not touch that metal since the negative charge repels them, deflecting them sufficiently to cause them to pass through the empty spaces provided for that purpose. But if the negative charge is high many electrons that would otherwise reach the plate do not pass through the grid at all. They are repelled when they come close to the grid and driven back again to cathode. If the charge on the grid were made sufficiently high the plate current would be zero, but it is not made that high. The grid bias is set at a very critical balance, so that an electron approaching the grid is attracted by the distant positive plate, and repelled by the negative grid just ahead, with almost equal force. Under these circumstances a very small change in the grid charge makes a vast difference in the number of electrons that are able to reach the anode.

Possibly an illustration will help make these simple facts even clearer, and prevent their ever being forgotten. Let us imagine a pair of very delicate, carefully balanced scales, with ten ounces in each pan. A one-ounce weight is then added to one of the two pans, and the other immediately rises. Ten ounces have been lifted by one ounc because the one-ounce weight upset a critical balance.

It is the same inside an amplifying tube. Whenever a few additional electrons are added to the charge of the grid, a great many electrons are prevented from reaching the plate, and repelled toward the cathode. Whenever a few electrons are taken from the charge of the grid, a large number of electrons that would otherwise have been repelled toward cathode are able to pass through the spaces of the grid and add themselves to the plate current. Every slight fluctuation in the charge of the grid is instantaneously duplicated in a corresponding but much greater change in the amperage of the plate current. A ripple, or a. c. component, is superimposed upon the plate current, that matches exactly every fluctuation of the speech-grid voltage that created it. The plate current ripple so produced is an amplified duplicate of the grid ripple.

That is the whole "secret" of amplification.

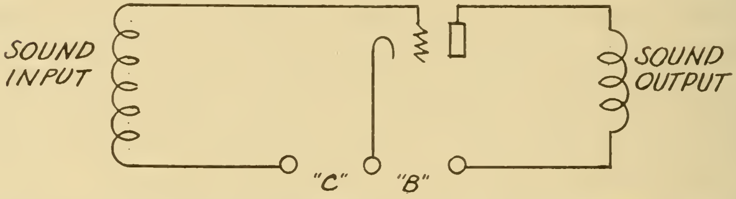


FIG. 189.—The arrangement shown here is the foundation of all amplifier circuits, regardless of how complex their details may be. The valve action of the tube permits the input circuit voltage to control the output circuit current.

(7) Figure 189 shows a simple amplifying arrangement with the plate and grid circuits described above. The filament-heating, or "A" circuit, which has no part in the amplifying action proper, is omitted.

Both of the circuits shown in Figure 189 carry fluctuating d.c., which may be regarded (Pages 35-36) as pure d. c. to which an a. c. component has been added. This latter is actually the case in the grid circuit, pure d. c. being supplied through the "C" terminals at the bottom of the drawing, and a. c. added by the transformer secondary marked "Sound Input." The a. c. component of the plate circuit is, of course, the ripple in the plate current created within the tube by the fluctuation of the grid charge. In Figure 189 both of these a. c. components must complete their circuit through the sources of d. c. supply (the terminals of which are marked "B" and "C"). But loss of volume and other disadvantages (as will be seen) arise from the practice of compelling sound a. c. to complete its circuit through the resistance of the d. c. power sources. Those disadvantages are avoided by the arrangement of Figure 190, which provides "by-pass" condensers to short-circuit the a. c. components around the d. c. sources. The condensers are of such size that they offer comparatively small impedance to the a. c. currents involved. The arrangement of Figure 190 is used in practically all modern amplifiers.

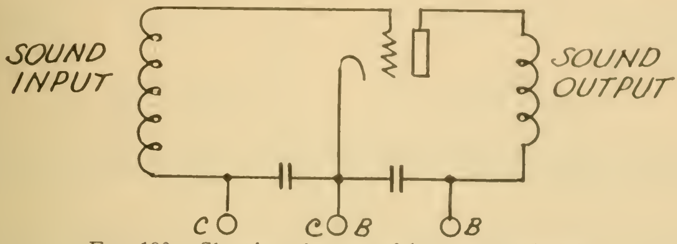


Fig. 190.—Showing the use of by-pass condensers

Inter-Tube Coupling

(8) No tube now available is so sensitive that photo-electric cell power applied to its grid will impart enough fluctuation to its plate current to operate a theatre-size loud-speaker. But the process that takes place in Figure 190 can easily be repeated by using the plate ripple in that drawing to modify the grid bias of another and more powerful tube. All that is necessary is to make the coil shown in Figure 190's plate circuit the primary of a "coupling" transformer, and then repeat the circuit of Figure 190 exactly. (9) This is done in Figure 191, which is a drawing of a "transformer-coupled" two-stage amplifier. Figure 192 illustrates "resistance coupling" between amplifying tubes. We have studied both arrangements in connection with the coupling of photo-

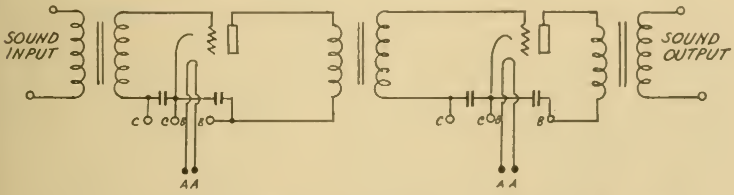


Fig. 191.—Transformer-coupled amplifier. (Compare Fig. 180.)

electric cells to their amplifiers (see Figures 180 and 181), and there is no need of rehearsing the electrical action in this place. Both methods of coupling are commonly used in theatre amplifiers, usually with some modification.

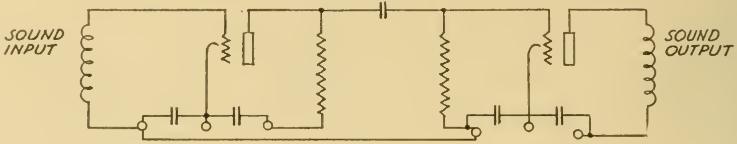


FIG. 192.—Condenser-resistor-coupled amplifier. (Compare Fig. 181.) This circuit, as well as Figures 189, 190, and 191, has series plate feet. Compare Fig. 193.

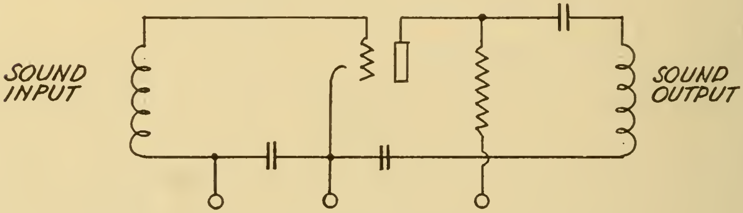


FIG. 193.—One-stage amplifier with parallel plate feed

Transformer coupling is often accompanied by "parallel plate feed," an arrangement shown in Figure 193. This differs from Figure 190 only in that the d. c. component is kept out of the transformer, permitting the use of a transformer that is smaller, less expensive and more efficient. Figure 194 duplicates Figure 192 except that the grid resistor of the second tube has been made variable, and hence serves as a volume control. When the variable contact in Figure 194 is placed at the top of the resistor the arrangement duplicates Figure 192 exactly. When the variable contact is moved downward less than the full a. c. voltage drop developed across the resistor is applied across the grid and cathode of the second tube. Hence changes in grid voltage are smaller, the plate current across that tube varies less, and the volume drawn from the amplifier is lowered. This is the commonest method of controlling amplifier volume.

The volume-control resistor of Figure 194 is usually built in a circle or a semi-circle, rather than as a straight line, and the adjustable contact is set by turning a knob, not by sliding it up and down as that drawing indicates. One maker has used a motor to turn the knob, thus making remote control of volume a practical procedure. The motor can be operated from any point of the projection room where a suitable switch is installed, or from the auditorium. Mounted on the same shaft is a separate set of contacts (insulated entirely from the amplifier circuits) that operate a group of signal lamps. These lamps act as volume indicators, advertising to what point the sliding contact of Figure 194 has been set. Such motor-operated volume control is the exception. In most amplifiers the slider is adjusted manually. In some there is no slider, but only a switch that gives choice of either of two positions along the resistor, low volume and high volume. Sometimes there is a switch of that kind between tubes 1 and 2, and a sliding contact as in Figure 194 between tubes 2 and 3, or vice versa.

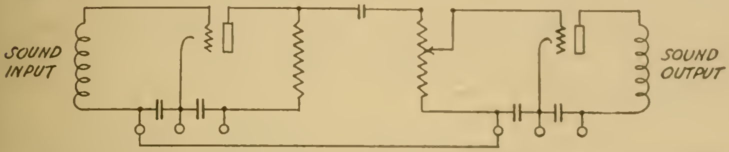


FIG. 194.—Illustrating use of coupling resistor for volume control

PUSH-PULL AMPLIFICATION

(10) Figure 195 represents a very common variation of Figure 189, in which two tubes are used in the same stage of amplification. (11) This arrangement offers some improvement in both volume and quality (giving somewhat more than twice the volume of a single tube) and is especially favored in the later, or power, stages of an amplifier. The grid bias (12) of Figure 195 is shared by both grids, but when speech a. c. is induced in the secondary of the input transformer the upper grid will grow more negative while the lower grid becomes less

negative, and vice versa. In consequence the plate current of the upper tube will decline while that of the lower tube increases, with corresponding reciprocity in the two halves of the plate transformer primary. This push-pull or see-saw arrangement is used in almost all theatre amplifiers. It is a very simple modification of the circuit of Figure 189.

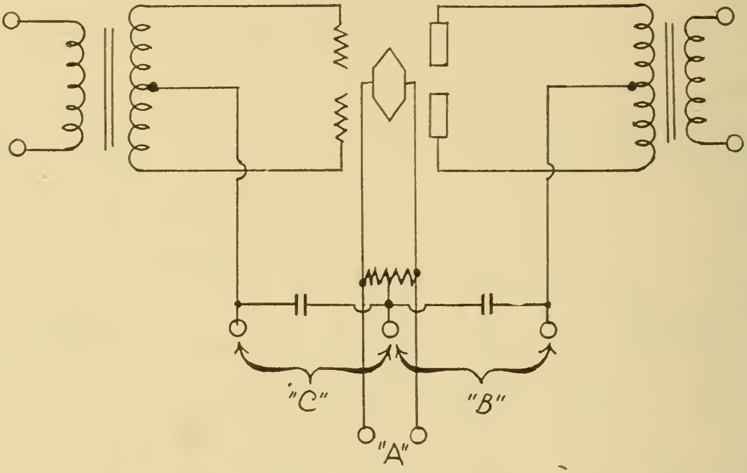


Fig. 195.—Circuit for push-pull amplification. Compare Fig. 184.

INTER-ELECTRODE CAPACITANCE

(13) We have noted before that the grid and cathode of a tube constitute two plates of a condenser, since they are insulated by vacuum and electrons do not strike the grid. The same is true of the plate and the grid. They are conductors, they face each other, they are insulated from each other—hence they constitute a condenser, and capacitance exists between them.

"Feed-back" may take place as a result of this capacitance. (14) Feed-back is the name given to the condition where changes in plate voltage, resulting ultimately from changes in grid voltage, are "fed back" to the grid by the grid-plate capacitance. Inter-electrode capacitance, and therefore feed-back, exists in all three-element tubes, but does no serious harm unless an attempt is made to secure excessive amplification. When that is done the three-element tube will distort sound by amplifying some frequencies more strongly than others. If the amplification, and therefore the feed-back, is pushed still further the tube will "howl" at the frequency it has amplified most strongly, and nothing will come from the speakers but a continuous whistle. (15) The tube is in a condition of "oscillation," that is, acting as a converter that uses its d. c. plate power supply to generate an alternating current of audible frequency. It is no longer acting as an amplifier, but as an oscillator.

A good theatre amplifier is designed with sufficient "loss" to make sure that the maximum volume control setting cannot possibly cause any tube to oscillate. (*Reverse feedback, or inverse feedback, described a few pages further on, is feedback in opposite phase, which does not build up volume to the point of howling, but reduces volume.*)

Increasing Amplification—Screen Grid Tubes

(16) To obtain more amplification per stage without distortion, and thus use fewer tubes, the design of the tube is modified to include a fourth element. This fourth element is the so-called "screen grid," and tubes containing it are "screen grid tubes."

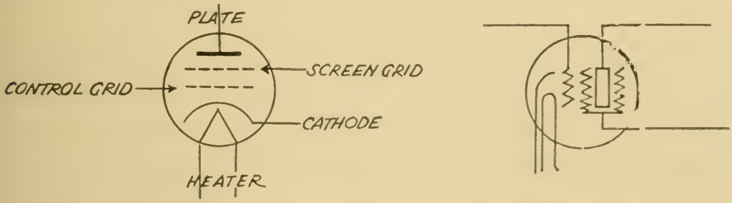


Fig. 196.—Screen-grid four electrode tube, or tetrode

(17) The screen grid completely surrounds the plate. When this element is built into the tube there is no longer any effective inter-electrode capacitance between control grid and plate. The inter-electrode capacitances are between control grid and screen grid, and between screen grid and plate. The screen grid is maintained at a positive voltage that is slightly lower than the plate voltage.

FIVE-ELEMENT TUBES

(18) Although the amplification of a tube can be increased by addition of a screen grid, even this improvement does not enable the tube to work at its maximum capacity. There still remains another limiting factor which is called "secondary emission." This is the emission of electrons from the plate, caused partly by the direct impact of electrons coming from the cathode, and partly by the fact that the plate is heated by the multitude of such impacts. The presence of a positively charged screen grid close to the plate encourages such emission. The "plate space charge," that is to say, the cloud of electrons that surrounds an emitting plate, repels electrons coming from the cathode and limits the "space current" across the vacuum.

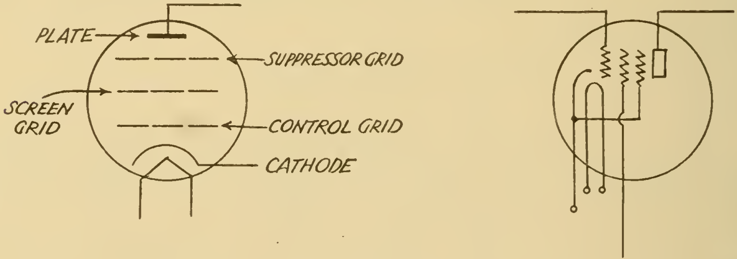


FIG. 197.—Five-electrode tube, or pentode

A fifth element may be introduced into the tube to prevent secondary emission. That addition creates a five-electrode, or pentode tube. The fifth element is the "suppressor" grid, which is located between the screen grid and the plate, and is negatively charged. The suppressor grid discourages secondary emission and drives any electrons that may escape into the vacuum back to the plate again. It thus destroys the space charge that surrounds the plate in a four-element tube, and permits still further amplification per stage.

Suppressor grids commonly receive their negative charge through direct connection with the cathode. In some pentodes this connection is made inside the tube.

However, in the 6J7-type pentode tube shown in Figures 200 and 201 it is made at the socket terminals.

(19) The three-electrode tube is often called the "triode," the four-electrode or screen grid tube is the "tetrode," and the five-element tube is a "pentode."

"CLASS A" AND "CLASS B" CIRCUITS

(20) Amplifier circuits may be either Class A or Class B. The difference is a matter of grid bias, but the constants of tubes, transformers and other apparatus must be adapted to the type of amplification used. Class A amplification is the kind we have been considering up to this point, in which the grid is always negative, and made a little more or a little less negative by the speech a. c., and the volume of the plate current varies or "swings" around a medium level. Circuits designed to operate in Class B commonly have a low grid bias, and when speech a. c. is added the grid "swings" positive during part of the cycle. In some Class B circuits there is no grid bias at all, and the grid is positive over full one-half of the speech current cycle. The plate circuit constants are so adjusted that there is a little flow of plate current while the grid remains at all negative, and a sudden rush of plate current results when it swings neutral or positive. The circuit of Figure 195 is often used for audio-frequency Class B.

Tubes originally designed for Class A work can sometimes be operated as Class B by providing a high grid bias; one so high that there is practically no plate current except during such time as the speech input is positive with respect to grid and the extremely negative bias is reduced accordingly.

The projectionist cannot expect to distinguish between Class A and Class B amplifiers by looking at them, or in most cases, even by studying their wiring diagrams. Manufacturers, however, grade their amplifiers as Class A or Class B. The large majority of theatre amplifiers are Class A.

Class B gives greater power per tube than Class A which can be understood when it is remembered that in

Class A amplification the a. c. component of the plate circuit is a comparatively small ripple upon the underlying d. c., while in Class B the "plate swing" is much greater; sometimes, as said above, the Class B plate current may vary from nearly nothing to the maximum during each alternation of the grid bias. Because of this difference small tubes can be used to provide sound for a moderately large theatre but the gain in economy is paid for in some sacrifice of quality.

(21) Class AB, sometimes called Class A Prime, represents a compromise between the two kinds of amplification above described. The grid bias is so adjusted that the grid charge will always be negative with low or medium volume, but at high volume the grid swings positive during part of the speech cycle. At low volume the tube will operate in Class A; at high volume in Class B.

All the foregoing represent essentially minor variations of the fundamental circuits shown in Figure 189, which are basic to every type of amplifier whatsoever.

It should be mentioned that these variations are combined in all possible ways. The same amplifier may have one stage of Class A and another stage of Class B, just as it may have condenser coupling between tubes at one point, and transformer coupling between another two tubes. The combination in one amplifier of single-tube stages such as Figure 189 with push-pull stages such as Figure 195 is extremely common. But Figure 189 still remains the foundation of all amplifying circuits. No superficial variations alter that fundamental fact.

Amplifiers and Their Power Supplies

Figure 191 represents a complete amplifier, and there are now amplifiers in theatre use that resemble Figure 191 in needing power supplies from an external source. The commoner practice, however, is to build the power supply equipment into the amplifier cabinet. Thus a typical amplifier includes not only the circuits explained above, but also a rectifier arrangement to convert 110-

volt a. c. to the d. c. of various voltages required by the tubes. We are now ready to inquire in detail into the power requirements of amplifying tubes.

PLATE POWER SUPPLY

(22) The plate of the amplifying tube uses d. c. only. In this the amplifying tube again differs from the rectifying tube. The function of the rectifying tube is to convert a. c. to d. c., and a. c. is applied to its plate for that purpose. But the function of the amplifying tube is to superimpose an a. c. ripple on steady d. c. Alternating current cannot be used for the plate supply of amplifiers, and the d. c. that is used must be extremely steady and pure. Any ripple it might contain would be heard in the loud speakers as sound.

The plate voltage runs from about 90 volts for small tubes up to about 1,000 volts. The maximum current per tube may be about 100 milliamperes, while the smallest tubes have a plate current of about 1 milliampere.

(23) Plate power for amplifiers can come from any of four sources. Dry batteries were used for small tubes, particularly for those of photo-electric cell amplifiers mounted on or near the projector. Storage batteries with a total of 350 volts have been used in some systems, although this method is definitely obsolete. High-voltage generators enjoyed a certain vogue, but are also obsolete or rapidly becoming so. The fourth method, now universally favored, is that of the built-in rectifier, using rectifying tubes, and amounting essentially to combining the basic circuits of Fig. 50 (page 112) and Fig. 195. The line a. c. is supplied to a power transformer built into the amplifier. A. c. drawn from the high-voltage secondary of this transformer is rectified, filtered, and supplied to terminals "B" of Figure 195. These terminals may actually exist in the amplifier, or wires may run solid from the rectifier filter to the amplifying tube sockets, since there is no real necessity for terminals when the power supply is built into the same cabinet or panel. If the panel carries amplifier tubes of more than one type,

requiring more than one voltage for plate power, the rectifier supplies the highest voltage necessary, and power for the smaller tubes is obtained by means of voltage drop through resistors included in the rectifier output circuit for that purpose. Screen grid voltage, which is commonly lower than the plate voltage of the same tube, is secured in a similar way. Sample plate supply circuits are traced in detail a few pages further on in this section.

Filament and Heater Supply

(24) Filaments may be heated by either a. c. or d. c., depending on the type of tube, while indirect heaters are usually supplied with a. c. Direct current is compulsory in some kinds of filaments. Filament and heater voltages are usually low, not more than ten volts. Current requirements range from a quarter of an ampere to about three amperes. One Western Electric rectifier tube, however, uses six amperes at fourteen volts. D. c. applied to the filaments of small tubes may be filtered to remove ripple.

(25) Four methods of providing heater or filament power have been employed. One is the external storage battery. Another is the external motor-generator, and a third the external rectifier. All these provide d. c. The commonest method provides a. c., and consists of a transformer with a low-voltage secondary and a 110-volt primary, built into the amplifier.

Very often this transformer, and the plate supply transformer mentioned above, are the same instrument. The same transformer can have more than one secondary, and it is common practice to provide a high-voltage secondary, consisting of many turns of wire, and one or more low-voltage secondaries, with comparatively few turns of wire, all on the same core. Such secondaries operate independently of each other. The voltage delivered by each secondary will be governed entirely by the ratio between its turns and the number of turns on the primary.

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GRID BIAS SUPPLY

(26) The grid bias must be smooth d. c. The voltage required is a small fraction of the plate voltage needed for the same tube. The current required in Class A is zero, since the "load" of the grid circuit is a condenser, through which d. c. does not flow. In Class B circuits there will be some flow of grid current when the grid swings positive.

(27) There are six methods of providing grid supply. The simplest is by use of a small dry battery, called the "C" Battery. This would connect to terminals "C" of Figure 189, negative to grid, and positive to cathode. A second method uses a voltage drop introduced into the d. c. filament supply (Figure 198). A resistor is wired in series between the negative side of the filament and the negative pole of the filament supply battery or other d. c. source. The grid is wired to the negative side of that resistor, and is therefore negative with respect to filament by the extent of the voltage drop the resistor creates.

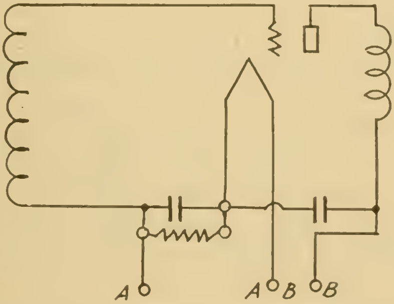


FIG. 198.—Method of obtaining grid bias by voltage drop in filament circuit.

The method of Figure 198 is not applicable to large tubes that need a grid bias of higher value than their full filament voltage. The circuit of Figure 199 is used with such tubes, as well as with heater types. The resistor shown in that diagram is in series with the plate or "B" circuit. The grid of Figure 199 is negative with respect to cathode by the extent of the voltage drop through the resistor.

BIAS CELLS

The grid bias cell replaces the old grid bias battery. The cell is also a battery, but doesn't look like one. It looks something like an acorn made of zinc and is about the size of an acorn. When several cells are used in series to obtain greater voltage, they are mounted in a single line along a special strip made for the purpose. A flexible clip contacts the anode, which is at the "top" of the acorn, in the center of a little ring of insulating material. If the flexible clip slips out of position and bridges the insulating material, the cell will be "short-circuited," and this is the first thing to look for in case of trouble.

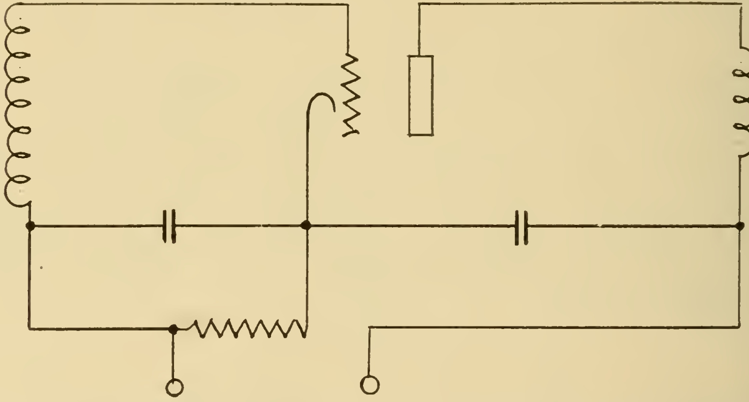


FIG. 199.—Method of obtaining grid bias by voltage drop in plate circuit

Unlike the old C-Battery, the bias cell has a rather long life and may give several years of service without needing attention or losing voltage. Bias batteries, or cells, of course never deteriorate through use. They are found only in Class A amplifiers in which the grid always constitutes an open switch, and no current whatever is drawn from them. (Use of a gassy tube provides an exception to this; gas conduction may permit a grid current flow amounting to some fraction of a microampere.) C-batteries as formerly used, though they never "wore" out, deteriorated partly through evaporation of their internal moisture, and partly through "local action," or a flow of current within the battery itself caused by the presence of impurities. The new bias cells are hermetically sealed and do not lose moisture. The materials are the same as those cited on pages 163-164, but exceptionally pure, reducing local action substantially to zero. Hence these cells, unless used with a gassy tube, should and do last for years, needing no attention of any kind.

Unlike the old C-batteries, they should *not* be tested often. Every test, whether by voltmeter or headphones, draws some small current from them, but since they are designed to deliver no current at all, each test seriously shortens their life. Unless high plate current, noisy sound, or some other trouble has been traced to the point where it seems possible a bias cell is at fault, such cells should never be disturbed.

THE BIAS RECTIFIER

This method of obtaining bias is especially favored in the case of Class B amplifying stages. (Refer to Fig. 199.) That diagram illustrates the method of obtaining grid bias that is by far the most widely used. Plate current flows through the resistor diagrammed in series with the cathode. The corresponding voltage drop across that resistor constitutes the grid bias.

Now suppose that, in response to the input signal, plate current increases. The voltage drop across the resistor also increases. Grid bias becomes more negative, and tends to choke back or counteract the increase in plate current. Conversely, when plate current declines, the grid bias falls off, and this has the effect of permitting an increase in plate current.

The bias resistor of Figure 199 could be chosen of such value as to counteract entirely the amplification of the tube. This, of course, is not done. Moreover, the by-pass condenser drawn just above that resistor tends to filter out irregularities in the current through the resistor, by-passing a fair percentage of them. The method indicated in Fig. 199 works well enough in Class A circuits and is widely used.

In Class B circuits, however, changes in the value of plate current are much more extreme, and the method of Fig. 199 is not satisfactory wherever the by-pass condenser cannot filter the changes in grid bias sufficiently to give entirely stable operation. On the other hand, bias cells or C-batteries are impracticable because grid current flows in Class B operation, and such cells or batteries would very soon be destroyed. They are in no way suited to circuits in which any flow of appreciable current is encountered.

Therefore a standard rectifier circuit is now sometimes used, in place of C-batteries, and in place of the circuit of Figure 199. There is nothing unusual about such rectifiers; they are standard half-wave or full-wave circuits such as are used in any amplifier to provide plate voltage. Their filtered d.c. output completes its circuit through a suitable resistor, and the voltage drop across that resistor, or a portion of it, is wired negative to grid and positive to cathode.

Grid bias obtained in that way of course is independent of changes in the plate current of the amplifying tube to which it is applied, and is therefore called fixed bias. The arrangement of Figure 199 is often called self-bias.

SEMI-FIXED BIAS

A still more recent method of managing grid bias avoids the use of a separate rectifier by compromising with that of Figure 199. In that circuit, the resistor supplies bias only to one tube. Instead of using a separate bias resistor for each stage, it is possible to return all the cathodes of an amplifier to a single resistor, which then returns to the negative terminal of the plate supply. That one resistor carries all the plate current of the amplifier. The current through it is therefore somewhat steadier than that of any one tube alone, and grid bias obtained from the voltage drop across such a resistor is called semi-fixed bias.

Usually the different tubes of an amplifier will need different values of grid voltage, and commonly the semi-fixed bias resistor is tapped at suitable intervals, and the different grids each connected to its proper tap.

METAL TUBES

Many amplifying tubes can be obtained either in metal or glass, as preferred. When any given tube first existed in glass, and a metal counterpart came into existence subsequently, a conversion table, issued by tube manufacturers, is used to determine which glass and metal-types correspond to each other. But when the tube is first issued in metal type, and a glass model is made available subsequently, the type numbers are the same in both cases, except that a "G" is added to indicate *glass*. Thus, the 6L6 was originally issued as a metal tube; and its glass duplicate is known as 6L6G.

The metal tube simply has an outer shell or envelope of special steel, in place of an envelope of glass. The internal arrangements differ only in details of mounting and insulating the elements. The principle of action is unchanged; the metal shell takes no part in the tube action. It is not the plate of the tube, as is sometimes imagined, but only the shield, and is grounded accordingly.

Metal tubes do not plug into all glass tube sockets, because the prong and socket arrangements may be different in detail. However, late models of glass tubes are now made with sockets corresponding to those of metal tubes.

The metal tube has several advantages, one being self-shielding. The external shielding of a glass tube cannot possibly be brought as close to the active elements, and is therefore less perfect. The metal tube as made at present also has some disadvantages. One of these relates to the insulation of the base leads, which of course must pass through the metal frame or shell. They are carried through hermetically sealed into small glass beads, and there is at present some tendency for that insulation to puncture at excessive plate voltages. A more important disadvantage is that the interior of the tube cannot be seen. Not only is there no way to see directly if the filament is lighted, but the internal blue glow that sometimes indicates a gassy tube, as later explained, is invisible A valuable warning of impending trouble is thus removed from the eyes of the projectionist. More elaborate and complete test equipment is therefore needed with amplifiers that use metal tubes.

Volume Expansion

If a sound track carries a sound which is normally so weak that a human ear can just hear it, and carries it at such volume that the audience will just barely hear it when it is reproduced, then the same track cannot be made to carry the maximum volume of a full orchestra, and even less a thunderstorm or other loud noises. The recording studio uses manual or automatic "volume compression" to confine volume within track limits.

Compensating volume expansion is now built into some theatre amplifiers. The arrangement is very simple, although puzzling on a diagram if one does not know its purpose. A tapped resistor splits the signal to be amplified, feeding it to two different circuits. One is the usual train of amplification, which one part of the signal follows in the usual way. The other part passes through a single stage of amplification, after which it is rectified by a rectifier tube. The division of signal usually occurs after the first stage of normal amplification.

The rectified signal just mentioned is led back to one of the later stages of normal amplification and applied as grid bias, *positive* to grid. It therefore opposes the existing grid bias of the tube to which it is applied, reducing that bias and increasing the output volume.

When the original signal is weak, this supplementary bias can do little to oppose the original bias of the tube to which it is applied, but when the original signal is strong, the supplementary bias has a very pronounced effect in increasing amplification.

In other words, the input signal operates an automatic gain control. The louder the original signal, the greater will be the gain. The maximum volume of the sound track is amplified much more strongly than the minimum volume. Volume expansion of this type compensates for the sound track's limitations, and will permit full-strength reproduction of any sound, however loud, if output tubes and speakers are able to handle it.

Automatic Volume Control

Automatic volume control (a.v.c.) as used in a speech amplifier differs somewhat from a.v.c. as used in radio receivers, and may be essentially the circuit just described, operating through a polarity-reversing switch that permits the supplementary bias to reinforce a grid voltage instead of opposing it. The result is that increased input volume *decreases* amplification, and output sound tends to maintain a steady level at all times, regardless of changes in the volume of the input.

A.v.c. of course is not wanted with sound film, but is used in theatres and elsewhere with the announcing microphone. It has several advantages. The artist may turn his face toward the microphone or away from it—volume from the loudspeakers will remain substantially the same. Blasting will not occur, and acoustic feedback between microphone and loudspeakers is much more easily controlled. The a.v.c. circuit is so designed that the compensating action is not complete—the artist must be permitted to change loudspeaker volume by raising or lowering his voice; but he must put a larger change into his voice to produce a smaller change in speaker output. It is advisable to equip his microphone with a separate volume control to assist him in obtaining the effects he desires.

Practical Amplifier Circuits

All of the foregoing can be illustrated, and any details that may still seem dubious will perhaps be made clearer, by detailed analysis of the circuits of actual theatre amplifiers. In the course of such analysis a few additional principles of amplifier action, not yet investigated, will present themselves and will be dealt with as they arise.

Fig. 200 is the circuit or schematic diagram of the amplifier contained in the cabinet shown in Fig. 186. The reader will note how closely this modern projection room circuit resembles that of Fig. 194. There is no difference in basic principle between the two circuits; the detailed differences will now be considered.

Coupling to the photo-cell is identical with that of Fig. 181. The condenser that is shown in Fig. 181 is the same as C-1, in the upper lefthand corner of Fig. 200. The "d.c." terminals of Fig. 181 are represented in Fig. 200 lower left-hand corner by terminals "+85V" and "Gnd." Resistor "B" of Fig. 181 and R-1 of Fig. 200 are the same. (Resistor A of Fig. 181 is located in the sound head, with the photo-cell.)

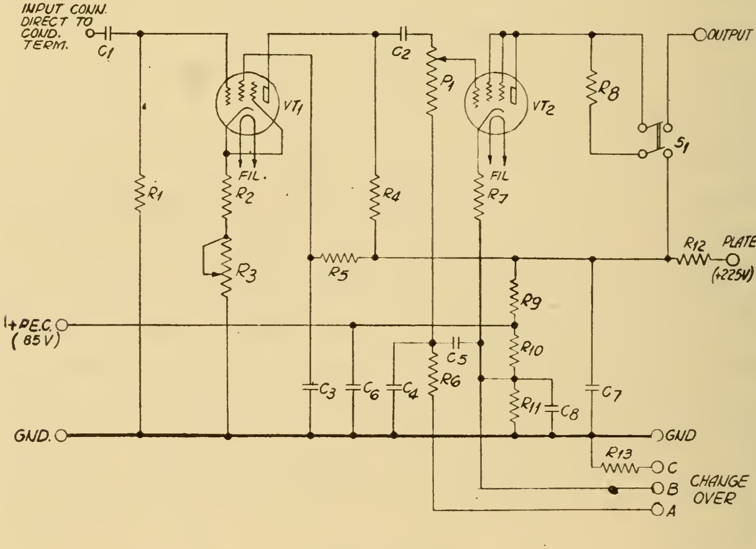


FIGURE 200

In tracing an amplifier diagram, it is generally advisable, however, to consider power circuits first and speech circuits afterward. In many drawings of this kind, filament or heater wires are omitted in favor of arrowheads. The plate power input terminal is shown at right, center. One branch runs up through R-8 to VT-2. A second branch runs left, up through R-4 to the plate of VT-1. Another branch runs left through R-5, and then up to the screen grid of VT-1. In each case the return is through the cathodes of the tubes to the ground bus. The amplifier also has a voltage divider, consisting of R-9, R-10 and R-11, from which 85 volts are tapped off for the photo-cell. C-6 serves as a filter condenser for that supply, while C-7 helps filter the entire B circuit so far as this amplifier is concerned.

The grid bias for the two tubes is obtained by the method of Fig. 199 with, however, the modification of a variable resistor, R-3, by which the bias of VT-1 can be altered to a limited extent. R-3 can be set to compensate for unequal volume from the two projectors. A different modification in VT-2 grid bias circuit is discussed below.

The speech input voltage across R-1 is connected directly across the control grid and cathode of VT-1. That tube is a pentode, with its suppressor grid connected to cathode externally.

Since the action of the tube is to superimpose an amplified speech ripple on the plate d.c. flowing across the vacuum, plate and cathode may be regarded as the poles of a generator of speech-frequency a.c. This speech output may be traced from the plate down through R-4, right, down through C-7 and back to cathode through R-3 and R-2. A parallel path runs right through C-2, down through P-1 and C-4, and then to cathode.

Still another parallel path can be traced from the slider of P-1 to the grid of VT-2, and from the cathode of VT-2 left through C-5. A portion of the speech voltage drop across P-1 is therefore applied to the grid of VT-2, exactly as in the case of Fig. 194. P-1 is therefore a volume control; the large dial or knob of which is illustrated in Fig. 186.

VT-2, although a pentode, and actually the same tube as VT-1, is in this case connected as a triode, the plate, screen grid and suppressor grid terminals being wired together at the socket. Using tetrodes and pentodes in this way is common modern practice. The speech output circuit of VT-2 can be traced down through R-8 and C-7 to the ground bus, and thence to cathode, with a branch circuit running through the output terminal at top right and returning through the ground bus.

One point not shown in this drawing is the nature of the photo-cell connection, which is by co-axial cable. This cable consists essentially of a pair of conductors, one of which is the flexible metal cable shield itself. Inside this shield is insulating material, and inside the insulating material is a single wire. The shield is grounded, the wire inside it connect to C-1 of Fig. 200. This type of cable gives better protection against picking up extraneous electrical disturbances that might be heard as noise.

Changeover terminals "A," "B" and "C" are externally switched so that in the operative amplifier "A" is jumped to "B," connecting VT-2 grid to the lower end of R-7 for normal grid bias, while in the non-operative amplifier VT-2 grid is switched to "C" and therefore to the lower end of R-11, raising the grid bias to cut-off, or the point at which VT-2 space current is substantially zero. This arrangement is traced in detail in Fig. 204.

Space will not permit tracing all diagrams that follow with the same attention to detail. Special points in connection with them will be fully explained. The reader should, however, be now able to apply the process just used in connection with Fig. 200 to any ordinary amplifier diagram, referring when necessary to the diagrams and explanations of basic amplifier action given previously in these pages. Similarly, the reader should be able to apply those basic circuits and basic principles to the amplifiers in his own projection room.

CIRCUITS OF FIG. 201.

This is the schematic of the power amplifier to which Fig. 200 delivers its speech output and from which it obtains its filament and plate operating voltages. Fig. 201 connects to the a.c. power line, as shown at the extreme lower right of the drawing. The power transformer and rectifier arrangements are entirely similar in principle to those of Fig. 51 (Page 114). The filter however, uses condensers only and has no choke coil. The positive terminal of the d.c. output is the filament of VT-5; the negative terminal the center tap of the power transformer plate winding; C-12 and C-21 are filter condensers; R-11, R-13 and R-14 constitute a voltage divider (R-11 being also the grid bias resistor for the two output tubes, with C-9 as its by-pass condenser corresponding to the left-hand condenser of Fig. 199). C-11 adds further filtering to the plate supply of VT-1 and VT-2, while C-10 does the same for the output plate power running to Fig. 200. R-12 and R-15 are meter resistors. Through R-12 the meter reads the joint space current of the two right-hand tubes; through R-15, the joint space current of the two left-hand tubes. Grid bias is obtained by the method of Fig. 199, also used in Fig. 200, and the screen grid voltage of VT-1 is wired through R-4, and is by-passed by C-4. The screen grid voltages of the

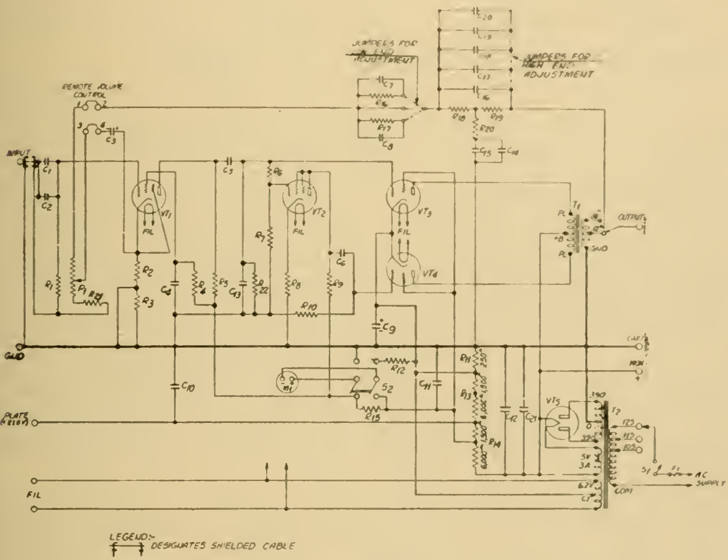


FIGURE 201

output tubes are obtained from the voltage divider, with the filter condenser C-11 as by-pass.

VT-1 and VT-2 are the same type tubes used in Fig. 200, 6J7's. VT-2 is connected to work as a triode. The two output tubes, however, are of a type not yet described.

Beam Power Tubes

The beam power tube has the construction of a tetrode but in addition possesses a pair of elements which we may call electron deflectors. The cathode is not round in cross-section, as is usual, but is oval-shaped.

Naturally, most of the emission comes from the flat side of the oval cathode; there is thus a tendency to form two beams of emission, rather than a scattering of electrons in every direction. This tendency is increased by the action of the deflectors, which are located at either side of the cathode, and at right angles to it. They are negatively charged by internal connection to the cathode (not shown in the drawing) and repel any electrons that may move toward them, compelling such electrons to stay with the main beams. The emission is thus formed into two concentrated beams, each moving toward one definite area of the plate surface. That area is recessed to receive them.

The purpose of the suppressor grid of a pentode is, (Page 95) to repel secondary emission. In the beam power tube, secondary emission will occur only at those portions of the plates that are subjected to the most intensive electron bombardment—that is, in the direct path of each beam. But those portions are recessed, and the concentrated beam of negative electrons entering the recess has the same effect as a negatively charged suppressor grid: it suppresses secondary emission.

A second feature found in beam power tube construction is the mechanical arrangement of screen and control grids. These spirals are so wound that in every case a turn of the screen grid lies directly in line with a turn of the control grid, and the positive screen wires are thus "shadowed" by the negative control wires. Since the control wires, being negative, repel electrons, very few reach the positively charged screen, but instead pass between the turns of the screen to the plate. Screen current therefore is unusually low. This feature, combined with the suppressor action already described, results in a tube of high-power output, high-power sensitivity, and extraordinarily high efficiency.

Phase Inversion

VT-2 is not an amplifier in the sense of adding to the volume of sound, although it does amplify. It is not intended to increase sound volume, but to act as a phase inverter.

To understand this function, refer to Fig. 195. In that diagram an input transformer with a center-tapped secondary makes it possible for speech current which is pulsating d.c. to be applied to push-pull grids as a.c. The accompanying description indicates that when the lower grid becomes more positive the upper grid becomes more negative, and vice versa, which is the indispensable condition for push-pull amplification.

Now in Fig. 201 it is desired to couple the pulsating d.c. output of VT-1 to the push-pull stage composed of VT-3 and VT-4. A transformer could readily be used, as in Fig. 195, but a tube is not only less costly, but lighter in weight, and can be made to serve the same purpose.

The plate output from VT-1 can be traced through several paths. One leads through C-5 right to the grid of VT-3 in the ordinary way of condenser coupling. Another leads through R-6 to the grid of VT-2. The amplified output of VT-2 is coupled through C-6 to the grid of VT-4. Since a tube's output speech voltage is always opposite in phase to its input speech voltage, VT-4 grid is 180 degrees out of phase with VT-3 grid—the same condition produced by the transformer in Fig. 195.

However, push-pull grid input signals must be equal in volume as well as opposite in phase, and the amplification added by VT-2 would upset the balance if not counteracted. R-6 and R-7 do the counteracting; together they constitute a volume control entirely similar to P-1 in Fig. 200, except for being factory-set and non-adjustable.

REVERSE FEEDBACK AND HARMONIC DISTORTION

For the distinction between fundamental and harmonic frequencies, refer to Chapter XV. For the present discussion, all frequencies on the sound track will be called input frequencies, and considered as if they were all fundamentals. To these input frequencies, every amplifier adds some percentage of new, alien harmonics, generated in the amplifier itself, which were not present in the studio sound, and are not desired in the loudspeakers, where they make the reproduction seem harsh and unnatural. Amplifiers produce this effect because the plate current fluctuation is never an entirely precise reproduction of the grid voltage fluctuation that produces it. There is always some little distortion of the wave-form, the effect of which is in every way the same as if the amplifier had added harmonics to all of the input frequencies. It is those new harmonics, and those only, which must be removed again.

One other preliminary point—all harmonics are divided into "even" and "odd." If the original frequency is, for example, 1000 cycles, there will be *even* harmonics of 2000, 4000, 6000 and so on; and *odd* harmonics of 3000, 5000, 7000, etc.

Even harmonics have always been kept down by the use of a push-pull output circuit (Page 195). In such a circuit the even harmonics meet in the primary of the output transformer 180 degrees out of phase, and so cancel each other. They are not transferred to the secondary winding, and only odd harmonics appear in the speakers. (This statement also refers only to extraneous harmonics generated in the tubes themselves, and has no bearing on input frequencies of any description.)

The preceding paragraph explains the statement, made in connection with Fig. 195, that push-pull amplification gives better quality.

The odd harmonics, however, are not removed by use of push-pull amplification. Reverse feedback, also called inverse feedback, reduces both even and odd harmonics generated by imperfections of amplifying tube action.

Ordinary feedback, occurring by accident in an amplifier, is explained on pages 494-495. The output signal finds its way back to an input circuit and undergoes repeated amplification. Under those conditions the only sound heard is that frequency at which the amplifier (including its unintended feedback path) is most efficient, and the amplifier is said to act as an oscillator generating that one frequency.

But if the output signal gets back to the input stage in reverse phase, it has a different effect, and what it does is oppose or partially cancel the original signal, reducing the output volume in proportion to the amount of feedback that is permitted to take place. The spurious harmonics introduced by the inaccuracy of amplifying action are especially reduced. By making the original amplification great enough to compensate for the loss of overall volume, the desired output level can be obtained at a very considerable reduction of the spurious harmonic content.

In Fig. 201 the output voltage developed between the center-tap and the lower terminal of the output transformer secondary can complete a circuit through two paths which have nothing to do with loud speakers. One path runs through R-19 and back to ground through R-20 and C-14, C-15. A parallel path continues left through the remote volume control terminals (here shown jumped, since no remote control is connected) through P-1 and thence to the grounded shield of the speech input cable. A third path runs from the slider of P-1 through condenser C-3 to the top of R-2. In consequence a portion of the output speech voltage is connected across the grid bias resistor of VT-1, where it acts to vary the grid bias in a phase relation 180° opposite to the input signal. Since inverse feedback has the effect of reducing overall volume, P-1 can be used within certain limits as a volume control.

Frequency Response Modifications

Fig. 201 includes frequency filters (Chapter XVII) by which the circuit can be made to discriminate for or against chosen bands of sound. C-2 is in parallel to C-1 (the drawing is defective in seeming to indicate that the left side of C-2 is grounded; this is not the case) to improve low frequency response. C-13 and R-22 by-pass some of the h.f. output of VT-1. More complex selective arrangements are included in the reverse feedback circuit, adjustment of which alters the degree of opposition which that circuit will offer to different bands of input frequencies. Open-circuiting C-14 decreases by-passing of high frequencies around the inverse feedback circuit, leaving that circuit more effective in opposing h.f. sound. Adding condensers C-16 to C-20 will also send more h.f. through P-1. Condensers C-7 and C-8 are of much higher capacitance, and primarily affect l.f. response. The reverse feedback circuit will be able to offer maximum opposition to l.f. with the jumper in center position, and least opposition (greater l.f. output) with the jumper at R-17. Jumper at R-16 gives medium l.f. control.

Care and Troubles of Amplifiers

Trouble-shooting procedures applicable to amplifiers as well as to other sound components are outlined in much detail in the trouble charts at the rear of this book. Routine maintenance, as distinct from trouble-shooting, is not covered in those charts, but will be discussed here. In addition, it will be well for the benefit of beginners to amplify the skeleton prescription of the charts with somewhat more detailed explanation of the ways in which the commoner trouble tests are actually applied under working conditions.

Amplifiers need special consideration only because the intricacy of their circuits sometimes makes trouble-shooting a long job, not because they are particularly delicate or troublesome items of apparatus. The contrary is true.

(28) Amplifiers contain no moving parts aside from switches, controls, and, rarely, an automatic relay switch. Even these moving parts are not used steadily, but only once in a while, and therefore are exposed to very little wear. Consequently, amplifiers do not wear out. They do, however, contain one part that is subject to deterioration, namely, the tube, which is consequently arranged to be replaceable, and which must be carefully watched. Aside from tube deterioration there are two other general causes of trouble in an amplifier. One is dirt, resulting in bad contact in the switches, the controls, and the tube sockets. The other is overheating, a condition that causes several different kinds of trouble which are described further on.

Amplifiers, then, need care in respect to three items: tube deterioration, dirt and overheating. Amplifier troubles arising from any other cause are comparatively uncommon.

CARE OF AMPLIFIER TUBES

(29) Tubes can go wrong in three ways, one being a burnt-out filament. But modern filaments very seldom burn out. They are made to stand up until long after the tube has become useless through decline of its emitting powers. A burnt-out filament is, moreover, a trouble that can be detected at a glance. Consequently the projectionist has little occasion to worry about it, provided proper care is taken to secure correct filament voltage. Excessive voltage, of course, will burn out any filament.

In most amplifiers, filament voltage control is provided only in d. c. filament circuits. There it is necessary. The d. c. source may perhaps be a storage battery, the voltage of which varies according to its state of charge. A filament rheostat is needed to insure that the voltage across the filament shall always be the same regardless of the condition of the battery.

Where filaments are lit by a. c., controlling rheostats are omitted as superfluous. The correct voltage is provided by the transformer and needs no adjustment as

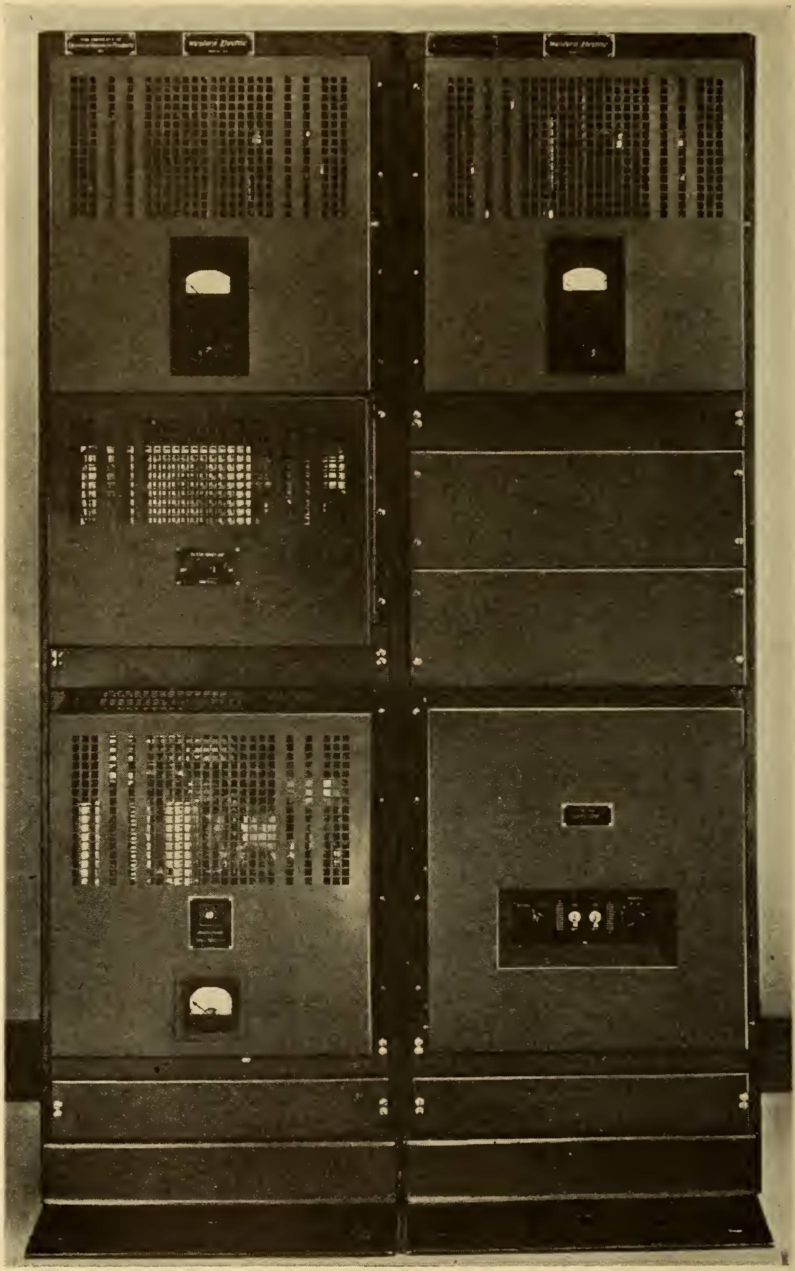


FIG. 202.—A high power amplifying rack. Compare with Fig. 219, page 594.

long as the power line voltage does not fluctuate.

In many houses, however, the line potential may vary from 85 to 135 in the course of one evening. This will happen wherever the local power house is underequipped, cannot maintain full output during the peak load of early evening, and does not cut down its output quickly enough when the peak load has passed. In such cases, which are common, the remedy is not to install a rheostat in the a. c. filament circuits, but to install a voltage control rheostat or transformer in the power line. If tubes are subjected to prolonged high voltage, even the heavy filament of a large tube is likely to burn out.

Much more common than the burning out of a filament is loss of the power of emission. This happens sooner or later to all tubes. While "rejuvenation" is possible, the method employed for that purpose varies greatly according to the type of filament involved, moreover, a mistake in rejuvenating is likely to result in stopping a show when the rejuvenated tube is put back into use. The common practice is to discard tubes when once they have lost emitting power. Tubes are no longer so expensive as to justify the time, effort and risk involved in attempting to restore them after they have worn out.

Loss of emitting power is revealed by a decline in plate current reading, plate voltage and grid bias remaining unchanged. It is usual to assume that those voltages have not altered, and merely to install a new tube whenever one in use shows low space current. Only when a series of new tubes all show low space current is it worth while to check the supply voltages.

In Fig. 201, meter M-1 can be used to reveal loss of emitting power, since it indicates space current values. As stated, the meter can be switched to read either the combined space currents of the two left-hand tubes or the total space current of the two right-hand tubes. If both readings show low, there must be some common cause, not loss of emission in a single tube. Loss of emission in VT-5, the rectifier tube, may be suspected, or low line voltage. However, if only one of the readings shows low, while the other is normal, one of the two sets of tubes tested is under suspicion, and the first step may well be to change *both* of the doubtful tubes. If the meter reading then returns to normal, the doubtful tubes may be replaced one at a time to find which one is faulty. Be sure to allow a cold tube of this size a minute or so to heat up to full emitting temperature before taking the reading—larger tubes than those here shown may require several minutes of heating before their emission can become normal.

It should be noted that in Class A amplification sound volume has no effect on the meter readings. Sound merely causes the space current to undergo a rhythmic rise and fall around some average value. The extent of that fluctuation represents the volume, but at all volumes the increase is equal to the decrease and the average current value remains constant. The meter cannot respond to current fluctuations as rapid as even the low frequencies of sound; it reads the average value only.

The same is not true of Class B amplification, where the sound is represented by very large fluctuations in space current and the meter will read the average of those fluctuations. Since they vary with volume, the needle will flicker. The same will happen to a small extent even in a Class A amplifier when driven to extreme volume, because in such cases the circuit is beginning to act as Class AB. Class A and Class AB space current readings are preferably taken with no sound present.

Push-pull tubes, as VT-3 and VT-4 of Fig. 201, should be matched. This can be done by substituting a new tube first in VT-3 socket and then in VT-4 socket, taking readings each time after the new tube has had a chance to heat. The difference in reading should be the same in each case. If one reading is substantially higher than the other, then the new tube is in a socket which formerly held a tube of low emission.

New tubes should not be paired in push-pull with older ones that, while still usable, have substantially lowered emission. Two new tubes should be used, and the one that is "still good but weak" marked and saved until it can be matched with another in the same condition.

The same matching requirements apply to full-wave rectifier tubes, Figs. 50, 51, for example. Rectifiers of the type of VT-5 of Fig. 201 can be checked with a portable test meter, if one is available, for internal match of its two halves; most such tubes do not have a common filament as shown in the drawing, but two separate filaments in one envelope.

Fig. 200 is typical of many amplifiers in that meters are not provided. Inserting new tubes and checking their effect on volume provides a very crude test. A better way is to use a portable test meter. The theatre can afford to buy this instrument; it will repay its cost many times over in case of trouble, and without trouble will pay for itself in a few years by economizing tube life and otherwise facilitating maintenance.

High space current is less common than the reverse condition, but more dangerous. It may cause the amplifier to overload, distorting the sound, and it endangers every part (for example, resistor R-9 in Figure 201) through which the excessive current must flow to complete its circuit. There are three general causes of high space current. One is high line voltage, which, connected across the primary of T-2 in Figure 201, or of T-1 in Figure 51, will generate excessive voltage in the secondaries of those transformers. The remedy for this condition has been mentioned. A second cause is a "gassy" tube, which must be discarded. A third is low grid bias, which is the commonest cause in amplifiers that use "C" batteries.

We have seen in connection with rectifier tubes (Page 93) that inclusion of mercury vapor gas increases the emission. Argon or other gas is intentionally added to photo-electric cells for the same reason. But gas is highly undesirable in amplifier tubes for the reason that the positive ions are too large and heavy to respond readily to changes in the grid charge. The presence of gas in an amplifier tube therefore upsets the amplifying action, and renders the tube unsuitable for use. Amplifier tubes are carefully pumped to the highest possible vacuum, and when the pump has done all it can a charge of magnesium is exploded within the glass to absorb any remaining air. But in spite of all precautions the crevices of the metal or graphite elements may retain some molecules of gas, that are dislodged when the tube becomes heated through prolonged use.

A blue glow partially filling the space of the tube, and flickering at high volume, indicates gas, but does not in itself indicate enough gas to be harmful. A strong blue glow combined with excessive plate current reveals a tube that should be discarded at once.

A steady or flickering blue glow in the glass itself does not indicate a gassy tube but only the presence of fluorescent materials in the composition of the glass, which have no effect on the tube action. To determine whether any glow seen is in the space between electrodes, and caused by gas, or only on the inner surface of the glass envelope and caused by harmless fluorescence, observe the tube carefully from several different angles.

It is of course impossible to look inside metal tubes; one that shows high space current can be checked only by replacement, or by several successive replacements as additional precaution against a "run" of gassy tubes, which is sometimes encountered.

Dirt in Amplifiers

Since the internal parts of an amplifier must heat somewhat with use, ventilation must be provided for them, and it is not possible to seal an amplifier so thoroughly that dirt will not get in. But the worst of all dirt for an amplifier is the fine carbon dust given off by the arc lamp. Carbon dust is the variable resistance used in the older type of microphone. Seeping into a sound switch or a volume control, or a filament rheostat, it will create variable resistance at those points, causing noisy sound. Perhaps the extreme seriousness of this type of trouble will not be plain to the reader (especially the beginner) unless he is reminded just how weak sound "power" really is. The power that fills every corner of a 4,000-seat theatre with loud, even thunderous sound, is not enough to light a 100-watt lamp. Yet even this represents an amplification of from ten to one hundred million over the original power delivered by the photocell. An extremely small amount of carbon or other dust in a switch contact, or a rheostat, or on the prongs of a vacuum tube socket, can create extremely disturbing noises in the loudspeakers of any theatre.

The remedy is to keep all switch contacts, rheostats, volume controls, vacuum tube socket prongs, and so on, scrupulously clean. Carbon tetrachloride is commonly used for this purpose because it dissolves grease readily, and it is only grease that holds dust to one place and prevents it being blown away. Chemically pure carbon tetrachloride gives better results than Carbona, which contains the same ingredient. The liquid of the projection room fire extinguisher also contains carbon tetrachloride—but don't rob the extinguisher, that may turn out to be suicide. Sound contacts should never be filed unless they are burnished afterwards. A very thin layer of vaseline is sometimes used to protect brass contact studs from becoming scratched. The thinnest possible film of vaseline is applied. This film is washed away periodically with carbon tetrachloride to prevent accumulation of dirt, and a new one applied.

(30) Dirt is not the only cause of bad contact in an amplifier. Another is loose spring tension. Spring tension is used at a number of points. The sliding contacts of rheostats and potentiometers (whether used as volume controls or for other purposes) are almost always dependent on spring tension. So are the prong contacts of "key" or "jack" switches of the telephone type, which are common in sound circuits, and some other switch contacts. And it is spring tension that makes every contact of every tube with its socket.

Contact tension may be destroyed by dirt, which has temporarily held the spring out of its correct position, or by use, or by the heating of nearby parts. It must always be watched, and restored as necessary. Restoration of spring tension is unfortunately not easy. In the telephone type of switch a special tool is needed to do a really good job of adjusting prong tension, and in the absence of that tool an extraordinary degree of care is essential. Careless work will result only in a bent prong, permanently useless. Much the same is true of rheostat and socket adjustments, except that with such apparatus care alone, without special tools, is usually all that is needed.

Poor soldering, especially during a hurried repair job, is another cause of loss of contact in amplifiers. Proper soldering for sound circuits is discussed on pages 62-65. The kind of soldering that is quite satisfactory for a 110-volt power line is not nearly good enough for the low-current speech circuits of an amplifier.

(31) It has already been explained that bad contact in an amplifier can result in noisy sound. It should scarcely be necessary to add that extremely bad contact may result in an open circuit in which all sound is lost.

Overheating in Amplifiers

(32) Two of the three chief categories of amplifier trouble, bad tubes and dirt, having been discussed in some detail we can now turn to the third major cause of trouble, which is overheating.

Overheating destroys the vulcanizing of rubber insulation and bakes the grease out of cotton insulation. Eventually it chars the cotton. All these conditions tend to the development of a short circuit. Overheating is very likely to boil the insulating compound out of transformer or condenser casings, leading to ultimate breakdown of those instruments. When extreme and prolonged it changes the crystallization of copper wire and may cause the wire to break, creating an open circuit.

The principal cause of overheating in amplifiers is excessive line voltage.

Hum in Amplifiers

(33) Hum at the frequency of the power line can be caused by three conditions. One is a defective rectifier tube. If either tube of a full-wave pair should burn out, or if the emission in either tube should so far decline that

the tube is essentially useless and the rectifier is a half-wave rectifier, hum might follow. The filter arrangement, having been designed for a full-wave output, is not capable of smoothing the heavier ripple of a half-wave rectifier. This condition, however, would also manifest itself in substantially lower plate current, and therefore in lower volume; consequently it could not escape detection for any great length of time if the projectionist is as alert as he should be.

Hasty repairs, in which wires are misplaced, can also result in amplifier hum. The wires of a sensitive sound circuit should never be placed in close inductive relation to an a. c. line, or to wires carrying the unfiltered output of a rectifier. Amplifier wiring is always planned to prevent inductive hum, and if it is disturbed for any reason must be replaced precisely as the manufacturer intended.

An uncommon but occasional cause of hum is a temporary defect in the power transformer, or in the choke coils of the brute force filter circuit. The cores of those parts are not solid pieces of iron, but are composed of a great many thin iron plates, called laminations. The laminations are held rigidly together by nuts and bolts, or by rivets, and if a bolt or a rivet should loosen, will vibrate in resonance with the frequency of the circuit. Such vibration increases the ripple in the rectifier output to a point where the filter cannot remove all of it. Tightening the holding bolts or the rivets will remove hum arising from this cause.

Use of Diagrams in Trouble-shooting

(34) Fig. 203 is the "wiring diagram" of the same amplifier of which Fig. 200 is the "schematic." (34) In practical projection room work it is highly important to work from a diagram like that of Fig. 200, rather than from the actual wiring or from Fig. 203. The latter shows all components and wires as they appear in the physical apparatus, with their electrical relationships completely obscured by their physical placement. There is no efficient way of studying Fig. 203 or its physical

counterpart. If Fig. 200 is not available, the most efficient procedure will often be to use Fig. 203 or the actual wiring as a basis for reconstructing Fig. 200, and then to study that!

Yet the circuits of Fig. 200 (and therefore of Fig. 203) are comparatively simple, as has been seen. The considerations just mentioned apply with multiplied force to the more intricate wiring of Fig. 201. A very competent man who has had extensive experience in amplifier work might make shift to get along with Fig. 203. The corresponding wiring diagram to Fig. 201 could hardly be printed on a single page of this book, without such great crowding of parts and wires as to make it unusable.

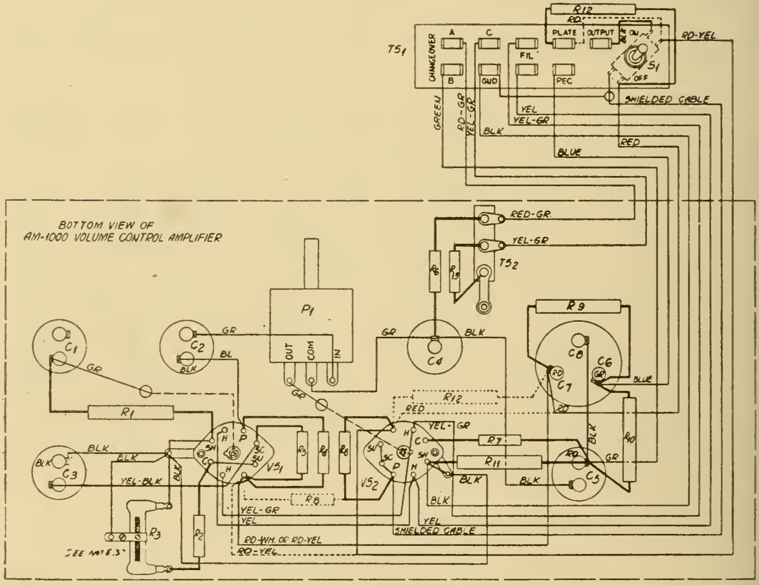


FIGURE 203

(35) The moral is, that if schematic diagrams of all sound equipment in the projection room are not on hand, they should be obtained. Most manufacturers will supply them. A few still will not. In that case, the only efficient way of dealing with serious trouble is to draw

the schematic by tracing the wiring. Since this takes a great deal of time, it should of course be done in advance. In other words, if the projectionist is responsible for sound results, and if he and his manager cannot obtain schematic drawings of the system installed, one of the first things to do is to make those drawings. Until they are at hand, shooting trouble may prove mostly a blindfold game of stab and miss, with no great hope of ever getting anywhere in particular.

However, if the reader should be caught with trouble and no schematic, he should note that a knowledge of, or schematic of, the *entire* amplifier may not be necessary. The trouble symptoms may or may not be such as to localize the fault to one part of the circuit, in which case that part only needs attention. For example, in Fig. 201 meter tests might show low or zero plate voltage at VT-1 only. Obviously the thing to do is to check the plate lead to that tube, for which purpose a schematic is not needed, or at most only a very abbreviated schematic, dealing with a few connections only. On the other hand, suppose Fig. 201 suddenly delivers distorted sound. With no knowledge of the circuit and no diagram of it, any man may find himself very nearly helpless. In those circumstances, the best trouble-shooter can do just two things. He can stumble through the wiring more or less blindly until a fragmentary, imperfect picture of Fig. 201 slowly builds itself in his mind, hoping for luck meanwhile; or he can proceed to draw Fig. 201 or such portions of it as seem necessary. The second method usually proves far the faster.

A further point in connection with schematic drawings obtained from the manufacturer is the need for checking them with the actual apparatus wherever there is any room for doubt as to the two corresponding. The apparatus may have been modified in some way since it was installed—a very common occurrence. Or the drawing, if obtained after the original installation, may incorporate improvements not actually present in the projection room. The manufacturer may be queried on this last point when the drawings are requested, but in every doubtful case the test meter should be used on the actual apparatus to resolve the doubt long before trouble occurs. The drawing is then modified as shown to be necessary. Every future change made in the apparatus is marked on the drawing. Cases are not uncommon in which trouble that should have been found in fifteen minutes required hours, or even days, to run down because drawings did not accurately represent the condition of the apparatus.

(36) Fig. 203, the wiring drawing, may at first thought seem somewhat useless, since the projectionist has the actual wiring under his eyes. In practice, the drawing serves a number of very valuable functions.

First, it labels every part with a symbol corresponding to the same symbol in Fig. 200. Those markings may or may not appear on the apparatus itself. They may be present on some parts, and not on others which are replacements installed during projection room repairs. They may have faded through heat, or become hidden by accumulation of dust. There may never have been any part markings; the manufacturer may have relied on putting a wiring diagram in the hands of his customers as being far cheaper and almost equally satisfactory.

Further, the parts so clearly indicated in a wiring diagram may be and often are hidden behind one another in the actual construction.

Again, the wires, so easily traced in the drawing, may very often be bound in a cable form, or run behind or under some parts, and thus be very difficult to trace in practice. Color-coding, which Fig. 203 indicates, is very helpful when equipment is new, but after some years some colors become too dirty to distinguish.

Lastly, it is easier to refer from Fig. 200 to Fig. 203, and then to precisely the part or wire wanted in the actual equipment, than it is to refer from Fig. 200 to the equipment directly.

Fig. 203, in short, is a convenience that saves time when time is important. It is less necessary than Fig. 200, and some manufacturers who supply schematics do not supply and in fact do not have wiring drawings.

They can be obtained from the majority of makers, however, and should be kept on file in the projection room whenever possible.

Wiring drawings, like schematics, should be matched with the existing equipment. Thus, in Fig. 203 two positions are shown for R-12, one in solid lines above the terminal block, at the very top of the drawnig, and one (in dotted lines) just above and right of VT-2 socket. These alternatives refer to different models of this amplifier. In Fig. 203 the solid-line wiring of R-12 corresponds to that of Fig. 200.

SWITCHING CIRCUITS OF FIG. 204

Fig. 204 shows the circuits of the changeover switch contained in the cabinet of Fig. 186, the same cabinet that also holds the amplifier of Fig. 200. It will be remembered that each projector is equipped with one of these front-wall cabinets, therefore there are two amplifiers of Fig. 200 to each system. Their outputs (marked "output" and "ground" in Fig. 200) are permanently wired to the "input" and "ground" terminals of Fig. 201. Sound changeover is not effected by switching these pre-amplifiers, but by rendering one or the other inoperative through alteration of its grid bias. Simultaneously, exciter lamps are switched, so that only one lamp at any given time draws current from the exciter lamp supply rectifier of the system.

Fig. 204 shows the switches of *both* front-wall cabinets, with their connecting wiring. The fact that these switches are two separate units is indicated by the vertical dot-dash line running down through the center of the drawing. It will be noted that the exciter lamps (extreme left and right) are similarly marked off.

The upper set of switches is concerned exclusively with the exciter lamps. There are three power input wires, marked "AC," "DC" and "Common." The lamp powered by d.c. is in the working sound head, the other is being pre-heated by a.c. so it will come to full brilliance without delay when switched into service. Tracing the wiring of these circuits will show that no matter how the switches are placed, throwing either one will reverse the existing exciter connections.

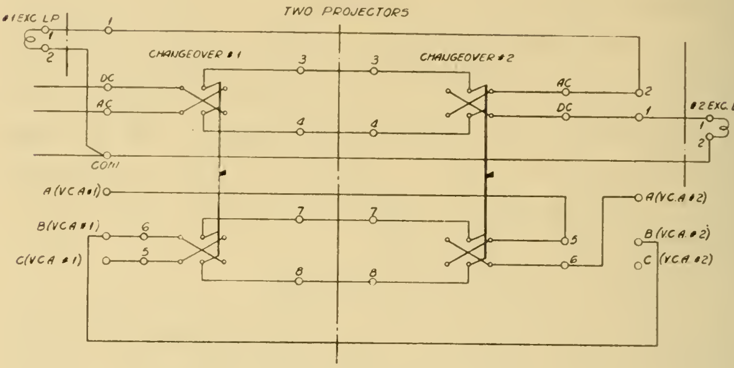


FIGURE 204

The lower set of switches move in synchronism with the upper set, and simultaneously switch the grid bias connections of the VT-2 tubes in the two amplifiers. Refer to Fig. 200. When Changeover Terminal A is externally joined to Changeover Terminal B, the control grid of VT-2 connects directly to the lower end of R-7 for normal bias. When the changeover switch open-circuits "B" and connects "A" with "C," the voltage drop through R-11 is added to VT-2 grid bias, raising the bias so high that space current in that tube is practically cut off, and no sound gets through.

Fig. 204 shows no external connection to "C" contact for "V.C.A. (volume control amplifier) No. 2." When that amplifier becomes inoperative its VT-2 grid returns to the common ground through the "C" terminal and the R-13 resistor of the *other* amplifier. As long as the ground is truly common, firmly connected throughout, that fact is unimportant, and the more so as it applies only to the amplifier which is not operating at the moment.

Fig. 205 is the wiring diagram of Fig. 204. The switch is at the right, marked S-2, the terminal board for external connections at the left. The lamp, top right, is the bullseye shown in Fig. 186 and not drawn in Fig. 204. It merely bridges across the exciter lamp connections, and therefore glows brightly when its associated exciter receives full operating voltage, and dimly when that exciter is standing by on the low voltage a.c. heating circuit.

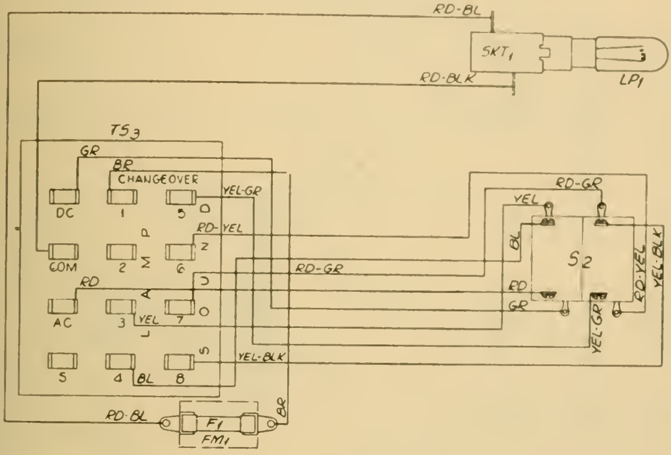


FIGURE 205

Figs. 200, 201 and 204 all relate to a single sound system, and do not exhaust all its circuits. It is obviously impossible to analyze in these pages even a few of the many sound systems now in use. The reader must study the drawings of his own equipment in the light of the basic amplifier principles which have been set forth. He will find that applications of those principles appear repeatedly in his own schematics, and that sufficient patience reference to those principles will make his schematics entirely clear and understandable, however intricate they may have seemed at first glance.

The complete sound system shown schematically in Fig. 205A may profitably be studied in that way by the beginner. Complex as it may seem, he will find nothing in it that has not been fully discussed in principle in the preceding pages of this Bluebook. A novice at trac-

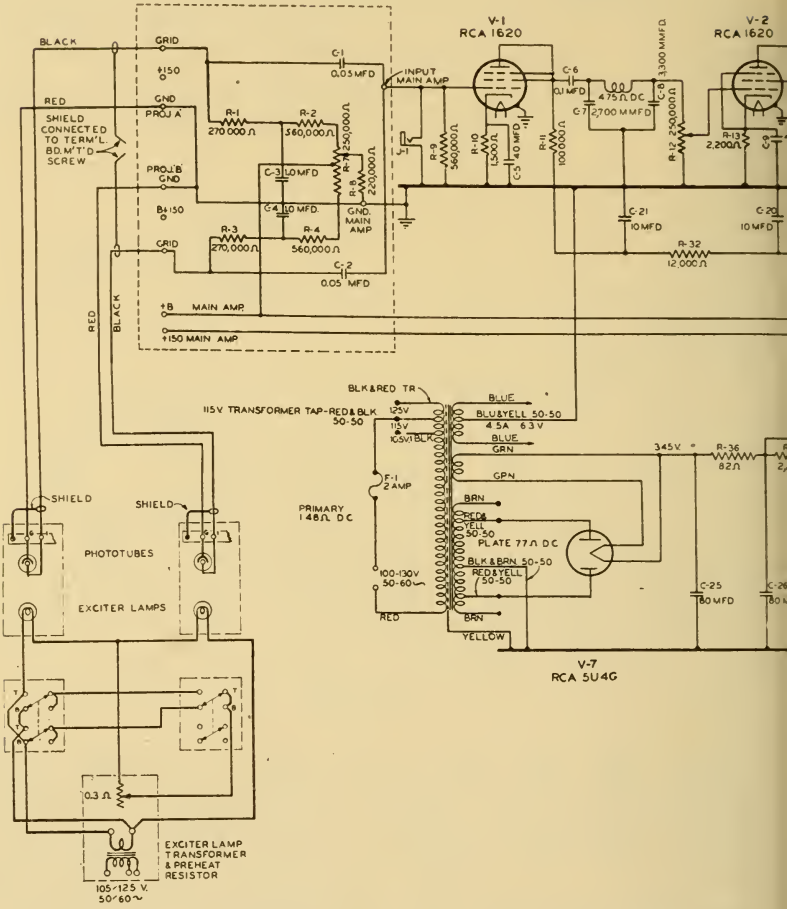
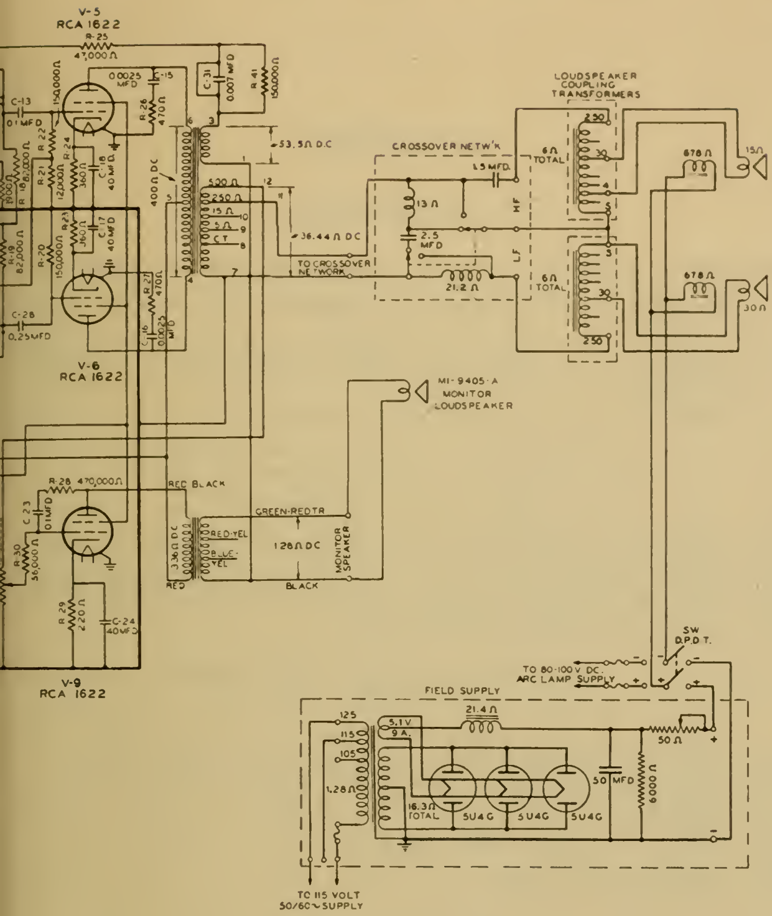


FIG. 205A.—A complete sound system shown schematically.

ing diagrams of this kind could well devote a total of half a day, at least, to a study of all the circuits of Fig. 205A.

Fig. 205A represents a complete sound system. The exciter lamp circuits are shown at lower left; the photoelectric cells just above them. The wires from the photocells run upward and right, through a voltage supply filter network to the amplifier input just left of V-1. The tubes shown along the upper portion of the drawing are all amplifying tubes; those along the lower por-



tion of the drawing are all rectifying (power supply) tubes. The phase inverter circuit runs from Terminal 3 of the output transformer to the cathode of V-3, the other leg of that circuit being the amplifier ground connections. V-4 is the phase inverter tube, corresponding in function to V-2 of Fig. 201 (page 513). The loudspeaker crossover network (pages 436-437) is shown to the right of the output transformer. The rectifier unit at lower right provides d.c. for the loudspeaker field coils (see Chapter XXII).

SPEAKERS

Practical Questions

(For answer to each question see statement of corresponding number in Chapter XXII)

1. Explain the construction and operation of a telephone receiver.
2. Explain the construction and operation of a magnetic speaker.
3. Does a magnetic speaker have a "field coil"?

THE DYNAMIC TYPE SPEAKER, PAGE 538

4. Explain the construction and action of a dynamic speaker.
5. What is the field coil? Describe four sources of supply for it.
6. What is the voice, or speech coil?

HORNS AND BAFFLES, PAGE 540

7. Why are horns used?
8. What are "directional baffles" and why are they used?
9. Why are flat baffles used?
10. What are cellular folded baffles?
11. Why are they used?

INCREASING SPEAKER FREQUENCY RANGE, PAGE 543

12. Why have separate l. f. and h. f. speakers?
13. Why are electrically flexible arrangements necessary in the transmission line to loud speakers?

SPEAKER CARE AND TROUBLES, PAGE 545

14. Name and explain three principal speaker troubles.
15. What precautions are needed in speaker transmission and supply lines?
16. What is meant by "poling" speaker units?

CHAPTER XXII

SPEAKERS

The simplest form of loud speaker is the common telephone receiver that anyone can open and examine, and almost everyone has. Equipped with a small horn, that instrument can furnish enough sound for a moderate-sized room, and when so used is essentially a magnetic-type loud speaker.

(1) If the reader has ever unscrewed the cap of a telephone receiver he has found underneath a disc, or diaphragm, of thin stiff metal. Under this, again, he found a horseshoe magnet, curved to follow the outline of the instrument, and two coils of very thin wire. The two coils of wire are wound around the poles of the magnet. When current flows through them they produce a magnetic field, which either aids or opposes the permanent field of the horseshoe magnet.

This much being clear, the metal diaphragm may be studied more carefully. When in operating position it is held firmly at its circular edge, while its center is pulled inward by the magnetic attraction. The metal of which the diaphragm is made possesses elasticity, and its center, pulled inward by the magnet, has a natural tendency to spring back toward neutral position whenever the magnetic attraction is lessened. If, on the other hand, the magnetic attraction is increased, the center of the diaphragm is drawn still closer to the pole-pieces.

In an instrument of this construction, a. c. or pulsating d. c., fed to the two coils, will cause the center of the diaphragm to vibrate in accordance with the frequency and strength of the current supplied.

Whenever the diaphragm vibrates it acts upon the surrounding air, pushing that out of the way when it moves outward, and leaving a vacuum into which air promptly rushes, when it moves inward. (Chapter XV.) In consequence, the vibrations of any unsteady current supplied to the coils of the receiver are converted, by the receiver action, into similar vibrations in the nearby air, which the ear will apprehend as the sound of words or music.

This instrument, however, is not capable of more than ear-volume unless it is equipped with a horn. Without a horn, high volume merely makes it rattle. The reason is not hard to understand.

When the receiver is operating under normal conditions, without a horn, air pushed out of the way when the diaphragm moves outward is pushed in all directions, and therefore offers comparatively small resistance to the diaphragm's motion. Similarly, when the diaphragm moves inward air rushes from all directions into the vacuum it leaves behind, and there is no very great disparity of air pressure on the two sides of the diaphragm to hinder its free motion. In short, the diaphragm, without a horn, is a motor moving without a load, and it moves easily and freely. If the volume is made high, the diaphragm will strike against the pole pieces each time it moves inward, and thereby add a rattling noise to the sound it creates.

When a horn is added the motion of the diaphragm meets greater resistance, since the neck of the horn confines the surrounding air and limits its freedom of motion. The diaphragm is then a motor operating under load. It moves through a smaller distance but imparts motion to a greater quantity of air, since the air immediately in front of it cannot slip away to either side. Therefore it creates a higher volume of sound (imparts greater energy to the air) without moving far enough to strike against its pole-pieces. In just the same way a motor running at high speed without load may wreck itself in doing less work than it would running safely at low speed with a full load.

THE MAGNETIC LOUD SPEAKER

(2) Magnetic loud speakers are used in theatres as

monitors. They should *not* be confused with "permanent magnet dynamic speakers" (later described). Magnetic speakers so called are essentially only large telephone receivers equipped either with a horn or with an oversize diaphragm which, as explained below, serves also to "load" the speaker. The magnetic speaker rattles like a telephone receiver when given more power than it should have. The permanent magnet dynamic speaker differs in details of physical construction as will be explained. By virtue of this different construction it can, size for size, handle much heavier overloads without rattling. (Certain troubles, however, will cause it to rattle, as hereinafter explained.)

The commonest type of magnetic speaker, and the type most often used for monitor work in the projection room, does not have a horn, but a "cone," which is a diaphragm from six to twelve inches across, usually made of paper. The magnetic fields of course cannot operate directly on a paper diaphragm. An armature is provided, consisting of a small bar of metal pivoted to respond to the fluctuating magnetic field, and connecting with the center of the diaphragm through a tiny lever. The elasticity of the paper cone pulls the armature away from the center of magnetic attraction, thus opposing the pull of the magnets. When the magnetic pull increases the center of the cone is drawn inward, and when the magnetic pull relaxes the elasticity of the cone causes its center to rebound outwards.

This arrangement needs no horn to provide a load for the diaphragm, since the area of the cone is large enough to act upon a sizeable body of air. At extreme volume magnetic speakers of this type will rattle, because the small metal armature will touch the pole-pieces if it moves far enough, but even a small speaker of this kind can produce sufficient volume for an average projection room before the point of rattling is reached.

(3) Magnetic speakers usually have two coils of wire, as most telephone receivers have (some have been made with three) but these coils are speech or voice coils. There is no field coil in a magnetic speaker, because its primary

field is provided by a permanent magnet. The function of the voice coil is, as explained, solely to oppose or to reinforce that field.

(4) The dynamic speaker is made to produce sound at high volume, and in consequence its diaphragm or armature must move through a relatively great distance, even when loaded by a horn or a cone of large diameter. Manufacturers have not, until recently, provided a permanent steel magnet of such strength that it would continue to exercise an even influence upon the moving diaphragm over appreciably wide distances. Instead, an electro-magnet was used in speakers intended to reproduce sound at high volume. The winding of the electro-magnet so used is the "field coil" of the dynamic speaker.

The voice coil of the same speaker commonly consists of a very few turns of wire, firmly fixed to the diaphragm. Alternating current is supplied to this coil through the output transformer of an amplifier. The voice coil therefore produces an alternating magnetic field, while the field coil, being supplied with d.c., possesses a steady field. During every cycle of alternating current that flows through its windings, the voice coil will be alternately attracted toward and repelled by the magnetic field of the electro-magnet. Hence the voice coil, and the diaphragm attached to it, will vibrate around the central, or neutral, position which they normally occupy by virtue of the mounting and inherent elasticity of the diaphragm. The extent and frequency of their vibration is governed (since the field of the electro-magnet does not fluctuate) solely by the amperage and frequency of the voice coil current.

(5) The field coil, which is the winding of the electro-magnet of a dynamic speaker, must be powered with relatively smooth d. c. If a. c. were used a powerful 60-cycle hum would be heard. If rough or pulsating d. c were used the pulsations would be heard in the sound. Perfectly smooth d. c. is not necessary, partly because the field coil of any speaker makes a very good filter choke, and partly because irregularities in the speaker field

supply are not amplified (while irregularities in the d. c. supply to a photo-cell, for example, are amplified tremendously). Moderately smooth d. c. is all that is required for speaker fields, and such current can be obtained from any of a number of convenient sources.

In theater sound systems the field winding of a loud speaker can be made to do double duty by acting also as a filter choke in the output circuit of an amplifier's rectifier. This method of powering the speaker avoids the necessity for a separate source of d. c. and saves the cost of an additional part for the filter. This is one modern method of providing speaker field supply, and is used in some of the more economically-priced systems.

A second method, one of the earliest used, is to power the field coil by means of a bank of storage batteries.

A third procedure, very widely followed, is to use either line d. c., or, where only a. c. lines are available, the d. c. output of the arc generator or rectifier. This method of power supply usually requires a resistance to reduce the d. c. voltage to the voltage needed. To make the power loss in that resistance as small as possible speaker fields are often wired in series. The resistance commonly takes the form of a rheostat, which can be adjusted to compensate for voltage variations in the supply source. Such a rheostat, together with an ammeter that is consulted in adjusting it, is often mounted in a metal box, the entire assembly being called a "horn field control cabinet," or by some similar name. Switches are usually provided backstage, by means of which any speaker field that may open-circuit can be shorted out at once; otherwise a break in one field winding of the series circuit would stop the show until the faulty unit had been replaced. The horn field control cabinet, mounted in the projection room, contains a similar switch to guard against open-circuit in the monitor.

A fourth method of powering speakers is by use of rectifiers which may be either of tube or of disc type. The combination vacuum tube rectifiers of Figure 51 has an output circuit (lower left) for speaker field supply. Individual rectifiers are also used for the purpose. In some cases these are mounted backstage, and are under care of the stage crew rather than of the projectionists.

(6) The voice coil (speech coil, speech winding) of the dynamic speaker is of course powered by the output of the last amplifier stage. It consists of comparatively few turns of wire rigidly attached to the diaphragm. It carries no core of its own, but in many speakers it moves in a slot, gap or recess provided for it in the core of the field winding.

The permanent magnet dynamic speaker was made practicable by the invention of new and more highly efficient magnetic alloys to replace steel. In physical construction this speaker resembles the electro-dynamic unit. Diaphragm and voice coil are entirely similar, and similarly related to the magnet. There is, however, no field coil, and no field excitation is needed. Powerful 18-inch speakers, each capable of providing enough sound for 2,000 seats, are now made in this way.

(7) Horns are used with dynamic speakers for two reasons. One is to "load" the unit when the diaphragm is of small diameter, as explained above in connection with magnetic speakers. The other is to provide a directional characteristic, which helps in securing equal and accurate distribution of sound throughout the auditorium.

(8) The directional baffle differs from the horn principally in that it is intended to load a larger diaphragm. The neck of the directional baffle is therefore not as small as the neck of a horn, but in other respects the instrument looks enough like a horn to be mistaken for one. It helps in obtaining even distribution of sound in a large theatre.

(9) Flat baffles are used with the larger diaphragms to obtain good reproduction of the lowest frequencies. All sound can be heard around a corner, out of sight of its source, but low-frequency sound is exceptionally nondirectional. When the speaker diaphragm moves forward it creates an area of compressed air in front of it and an area of rarefied air behind it. If the sound is of low frequency the compressed air will ooze right around the edge of the speaker into the region of rarefied air. Com-

pression and rarefaction will cancel each other, and the low frequency sound will be lost. Cone-type speakers not equipped with horns or baffles nearly always sound "tinny" because of this loss of low frequencies. Such speakers are "baffled" by mounting them against a circular hole cut into a flat board of sufficient area. This conserves the low frequencies; it also helps to load the diaphragm, inasmuch as the air being moved, while it can slip sidewise, cannot slip backward into the area of rarefaction. The dimensions of the baffle are governed by the lowest frequency desired. The lower the frequency, the greater the area of the baffle must be.

"Folded" and Cellular Baffles

((10) Figure 206 and 207 show the most modern form of theatre baffles, the cellular and folded types. The h.f. baffle is the smaller assembly at the top of each picture. It consists, as can be seen, of a cluster of 15 trumpets so united at their throats that they receive sound from only two speaker units. Another common h.f. form resembles a large trumpet divided by internal partitions springing from the common throat. See Fig. 208. The low-frequency baffle of Figs. 206 and 207 is more properly called "folded" by reason of its construction. Sound leaving the speaker diaphragms must follow a zig-zag path to the front of Fig. 206.

(11) The h.f. baffle in these illustrations serves only a single purpose in addition to loading the unit; the l.f. baffle serves two purposes.

The upper baffle effects superior distribution of high frequency sound. As already stated, the lower frequencies have the greater tendency to travel around corners. The higher frequencies exhibit somewhat of a beam effect. They are propagated more nearly in a straight line. With earlier types of speakers, securing proper distribution of the high frequencies was usually a serious sound problem. They tended to remain bunched in rays or beams, one beam for each speaker used, and seats located outside the beams did not receive maximum sound quality. The h.f. baffle of Fig. 206 produces 15

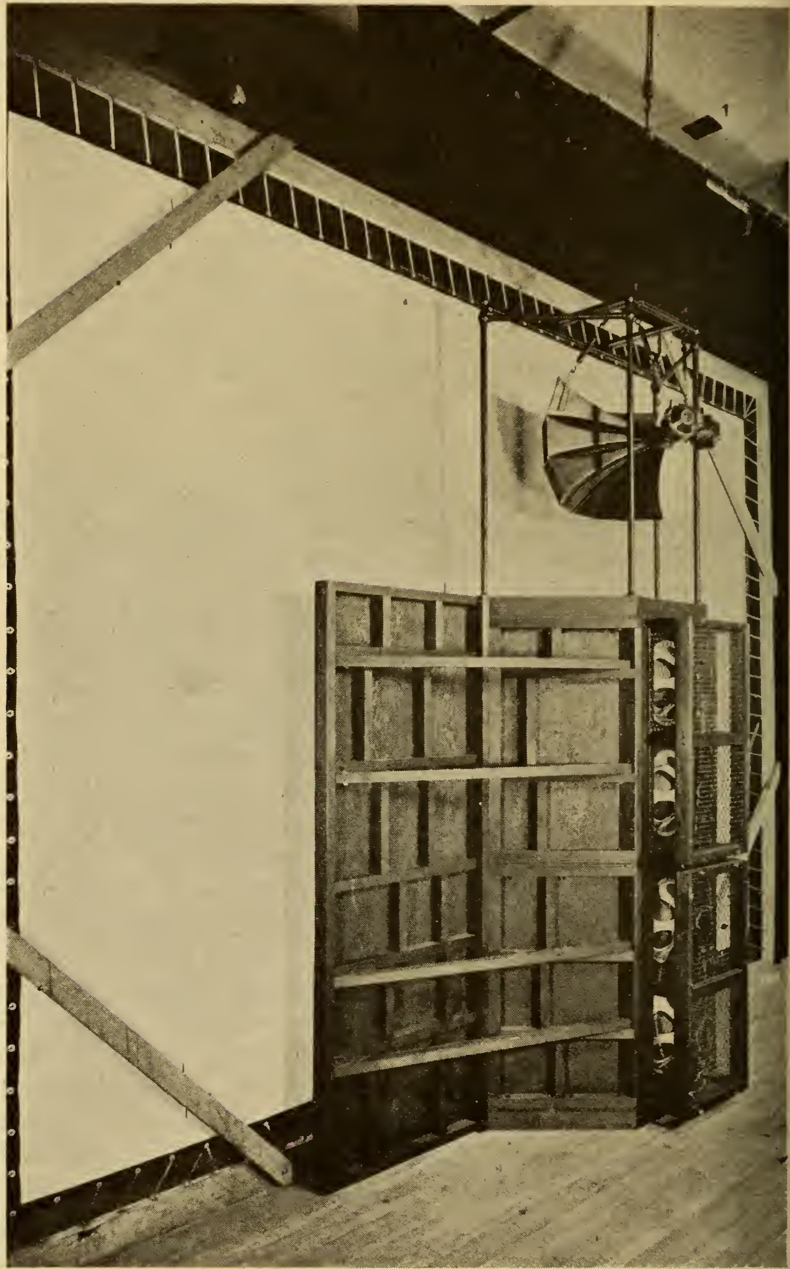


Fig. 206.—A modern speaker installation. Compare Fig. 207

beams, delivering h.f. sound to 15 separate areas of the theatre, in other words, to practically every seat. In very large theatres, two or more of these baffles may be used.

The low frequency baffles also distribute their sound output, but they have another function equally important. It was pointed out, in connection with flat baffles, that the reproduction of lower frequencies is achieved by increasing the baffle area. What is really increased is the length of the path the sound must follow from the front to the back of the speaker diaphragm. The longer that path, the less the chance for areas of compressed and rarified air to mingle and cancel each other. The folded construction of the lower baffle in Fig. 206 provides a very long sound path without requiring too much depth of space behind the screen.

(12) The necessary length of internal sound path of course could not be provided by the small, upper cluster of units in Fig. 207. The large lower baffle could not be made to give the same wide spread to h.f. distribution without a more elaborate and more expensive type of construction. Further, the use of separate l.f. and h.f. speaker units and baffles facilitates adjustment of the relative volumes of the two bands of frequencies, which can be modified to suit acoustic requirements. (13) For this purpose electrically flexible "networks" are introduced into the loud speaker transmission line, or, where there are separate l.f. and h.f. output amplifiers, into the transmission line leading to those panels. Such networks are described in the section dealing with "The A. C. Transmission Line."

The two baffles of Fig. 207 must be "phased." A sound consisting of several frequencies has been divided into two parts, one of which is reproduced through each baffle. If the l.f. part reaches the ear of the listener a fraction of a second later than the h.f. part, or vice versa, reproduction will be decidedly unnatural. To re-unite the two parts of the original sound in correct phase, the h.f. unit is moved toward or away from the screen until sound in the auditorium is satisfactory.

With the use of cellular baffles the "prolonged and patient work in pointing and repointing the speakers" mentioned in Chapter XV is greatly reduced from what it was with earlier types of equipment. However, precisely because sound is more equally distributed to all parts of the theatre, better acoustic qualities are required of the auditorium, and in some houses modern equipment

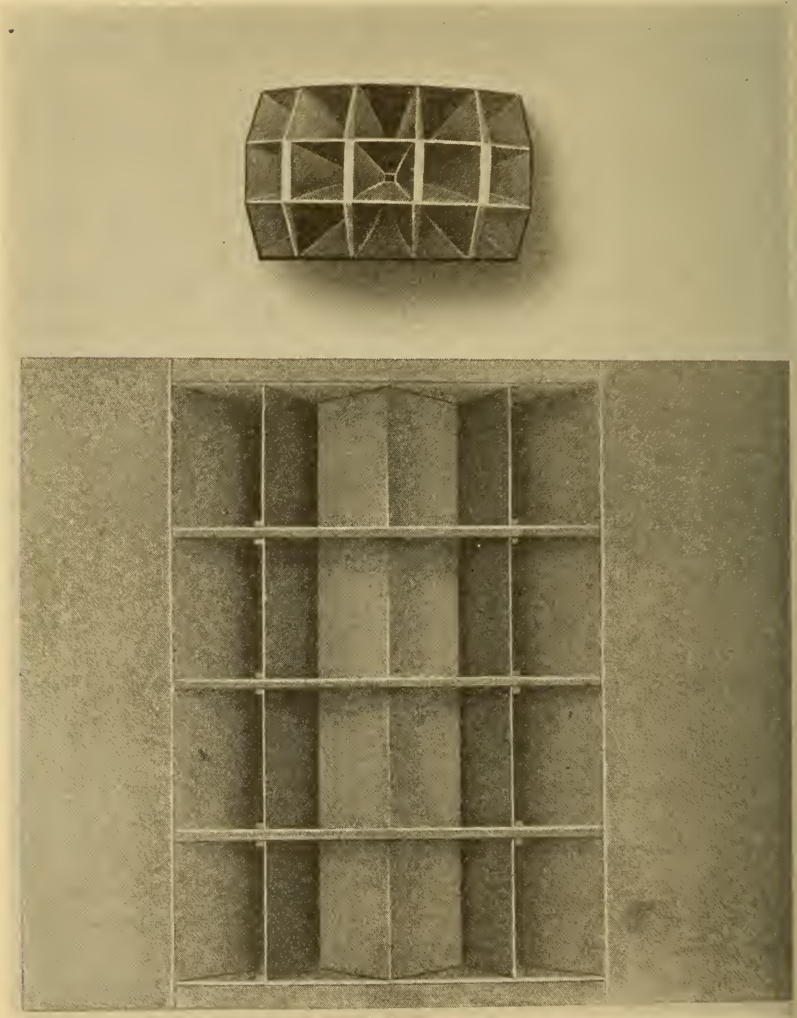


FIGURE 207

cannot be made to deliver its best quality until the auditorium has been acoustically treated. Such treatment may consist of replastering, or of installing more heavily upholstered chairs, or of changing the shape of some wall or ceiling surfaces. On the other hand, nothing more may be needed than hanging a few soft drapes at critical points. Only a trained acoustical consultant can prescribe the most effective and least costly procedure.

TROUBLES IN SPEAKER UNITS

(14) Damage to the voice coil, to the diaphragm or to the speech coil may either impair the quality of sound obtained from a speaker, or render it entirely inoperative.

The voice coil may burn out, but this trouble is not very common. However, prolonged and excessive volume, especially at low frequencies, may cause it. Open circuit in a voice coil is rather more likely to be caused by a break at the point where flexible leads are joined to it. The continuous vibration of the coil may break that connection. In some makes of speakers a break at that point can be re-soldered, in some it cannot. In some the construction of the leads is such as to make a break of that kind impossible.

It is a peculiar and interesting fact that in some makes of speakers excessive field current will ruin the voice coil. This has been known to happen where the construction of the unit is such that the voice coil moves in a narrow slot provided for that purpose in the core of the field. Excessive current through the field coil overheats both that coil and its core. When the slot in which the voice coil moves becomes too warm, the cement or glue that holds it to the diaphragm softens and sticks to the sides of the slot, and the coil tears.

The field coil, on the contrary, is commonly wound of heavy wire, little subject to open-circuit, and in a good speaker very seldom gives trouble unless excessive voltage is applied. It is the field coil supply, rather than the winding itself, that needs watching.

The diaphragm, as a moving part subject to great and continuous strain, is the most delicate part of the speaker.

A diaphragm that has become loosened, bent or warped, lost elasticity, or slipped off center, will damage sound quality. It may rattle, or create raspy sound at some one frequency or at high volume. It can seldom be repaired, and in most cases is replaced. Trouble of this kind can usually be heard at once. Where there are several speakers, however, it may be necessary to listen with an ear close to each, until the faulty one is discovered. If two speaker units are mounted on a double-throated horn one must be turned off to trace trouble of this nature.

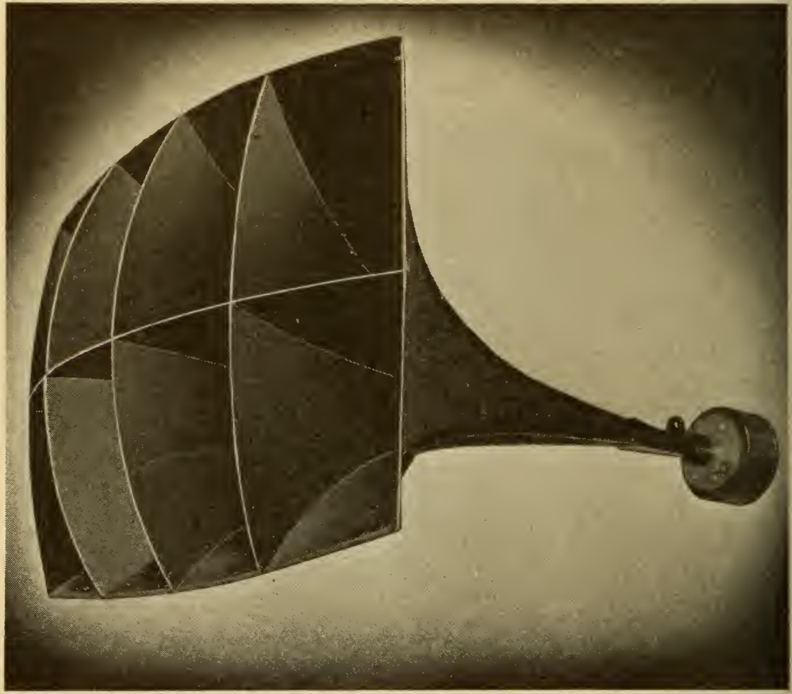


Fig. 208.—Compare with Figs. 206 and 207

Transmission Line Troubles

(15) The transmission line can cause bad sound through improper or impermanent network settings. Impedance mis-match can be created if speakers are

replaced carelessly with others of a different make or type. Such replacements may call for changing the output transformer of the amplifier, or a satisfactory adjustment may be made by choosing a suitable speech transformer to be mounted on the speakers themselves, but it is not possible to wire speakers to an amplifier promiscuously and expect satisfactory results.

Stage cables leading to the speakers may prove a serious source of trouble if the stage is used for vaudeville or other entertainment, and the cables subjected to being stepped on. Sooner or later they will resent such treatment and stop a show. Wherever the stage is in use all speaker supply cables should be run overhead.

Pin connectors are sometimes used when speakers have to be moved offstage to make room for a show. These also are a source of possible trouble. Looping the supply cables overhead makes their use unnecessary.

POLING SPEAKERS

(16) Whenever more than one speaker is used it is vitally necessary that all diaphragms move inward and outward in synchronism. If the diaphragms move in opposite directions the sound waves they create will be 180 degrees out of phase and most of the volume will be lost. Consequently speakers are "poled" or "phased"—that is, connected in the same polarity. Both voice and field lines must be poled. Voice contacts are usually marked, often with numbers. All the number 1 terminals should be connected to the same side of the output transformer secondary; number 2 terminals to the other side. Sometimes the wires are not numbered, but color-coded. Field coil terminals are commonly polarized + and —, and should be so connected to their power sources.

When speakers of different manufacture are used together reliance on marked terminals may not prevent incorrect poling, and it may be necessary to experiment with reversing polarities to determine which connection gives the best results. When the correct arrangement has been found the speaker terminals and connecting wires should be tagged accordingly.

DRIVES

Practical Questions

(For answer to each question see statement of corresponding number in Chapter XXIII)

1. What two different classes of mechanism are needed to move the sound film or the disc turntable?

Drive Motors, page 550

2. What is required of a drive motor?
3. What are "wows"? What is "flutter"?
4. What is the most common type of drive motor?
5. Why is it successful?
6. Is a synchronous motor used to drive a non-synchronous turn-table?
7. Are synchronous motors used in theatres where only d.c. is available?

Motor Speed Controls, page 552

8. Name four methods of controlling motor speed.
9. What is centrifugal speed control as used with d.c. motors? Explain how it works.
10. How does motor speed affect the centrifugal contacts?
11. What are "motor control cabinets"?
12. Explain the action of a motor control cabinet that has no tubes.
13. Explain the action of a motor control cabinet using vacuum tubes.
14. What is "hunting" in a motor?

Drive Transmissions, page 568

15. What is the drive transmission?
16. What is required of the drive transmission?

17. What is a "damping device"?

CARE AND TROUBLES OF DRIVES, PAGE 571

18. What care do projector motors require?
19. What maintenance is needed by speed control devices? What is the greatest help in tracing their troubles?
20. What attention does the drive transmission need?

CHAPTER XXIII

DRIVES

(1) To move the sound film, or the disc turntable, two classes of mechanism are required. One is the driving motor. The other is the transmission, consisting of gears, chains or pulleys, or combinations of all three, by means of which the motion of the motor is conveyed to the disc turntable or to the sprockets that move the film.

It will be logical to postpone discussion of the transmission mechanism until the motors that drive it have been considered.

(2) Four things are required of a modern projector drive motor. (a) It must be sufficiently powerful to perform the work. (b) It must possess moderately strong starting torque (torque is rotary force) in order to bring the projector up to speed promptly and avoid sloppy changeovers. On the other hand, the starting torque must not be so great that the mechanism is started with a jerk that might strip or weaken the teeth of the gears, or tear the film. (c) It must revolve at precisely the same speed as the motor with which the recording was made, neither slower nor faster, otherwise music will be off key and voices out of proper pitch. (d) It must impart an absolutely steady and unwavering speed to the film or record.

Slight fluctuations of motor speed are distinctly audible, and spoil sound completely. Since the pitch of reproduced sound depends entirely on the speed of the motor (Chapter XVIII), fluctuation of motor speed will make a steady note sound like a rapid succession of two different notes, one somewhat lower or higher than the other. (3) If the motor speed fluctuates rapidly this condition is called "flutter." If the change in speed takes place more slowly, creating a continuous, sighing change of pitch, the condition is called "wows."

To repeat, the four requirements of a good drive motor are:

(a) Sufficient power.
(b) Proper starting torque.
(c) Correct speed.
(d) Absolutely steady, uniform motion.

The special methods that secure these results from electric motors used for sound projection are described in detail in the paragraphs following, but the principles of motor action as such, apart from special means used to secure special results, cannot be discussed here. There are so many different types of electric motor that a book larger than this would be needed to do justice to that subject. Such books are available in any public library. There would be little value in taking a small amount of space from matters pertaining specifically to projection in order to devote it to a sketchy and inadequate account of motors. The fundamentals of motors have already been discussed elsewhere. Here we are concerned only with methods, peculiar to the projection room, that are used to secure exceptionally accurate and steady control of motor speed.

(4) The synchronous motor is the type most widely used for projector drive. The speed of this motor depends entirely upon the frequency of the line that supplies it. Increasing the load to be moved cannot slow down the motor, although it may stop it altogether. The current through its windings has no effect upon its speed, hence its action is independent of line voltage fluctuation. If the line voltage should become too high the motor might conceivably burn out, or if the line voltage should fall too low the motor might stop, but its speed can never vary unless the line frequency changes. The very simple reason for these facts is explained fully in any good book on motors.

(5) Synchronous motors for projector drive have proven successful because power companies regulate their frequency very carefully, even when they allow

their voltage to vary enormously. Frequency regulation is a matter of dollars and cents to a power company. All their generators, line transformers and other apparatus are designed for maximum efficiency at rated frequency, and permitting the frequency to vary means unnecessary losses. Frequency control of power lines has been so improved during the last few years that a frequency-controlled projection motor can be relied upon, in most American theatres, to maintain constant speed at all hours of the day or night.

(6) Synchronous motors are often used to drive the non-synchronous turntables in the projection room. There may seem on the surface to be some confusion at the idea of a synchronous motor driving a non-synchronous turntable. The facts are that the motor is synchronous because it operates in synchronism or resonance with the line frequency, while the turntable is non-synchronous because the sound taken from it is not synchronized with a moving picture.

(7) Synchronous motors are not used where only line d. c. is available. In theatres not equipped with alternating current a converter driven by d. c. can be used to generate alternating current for the operation of an a. c. amplifier. But the frequency of the alternator's output will not be absolutely constant unless its speed of operation is held absolutely constant. Why trouble to regulate the speed of a d. c. motor driving an alternator? It is as easy to regulate the speed of a d. c. motor driving a projector, and a smaller and less expensive alternator can be used to operate the amplifier only.

Synchronous motors are also omitted from the equipment of theatres that show silent pictures occasionally and may wish to vary their projector speed. The speed of a truly synchronous motor cannot be varied.

(8) The use of the synchronous induction motor is only one method of securing proper projector speed. Three other methods of obtaining the same result are in common use. There are "centrifugal" speed governors, used at present only with d. c. motors. There are motor control circuits involving vacuum tubes, used with both

d. c. and a. c. motors; and motor control circuits not involving vacuum tubes that are used with a. c. motors only.

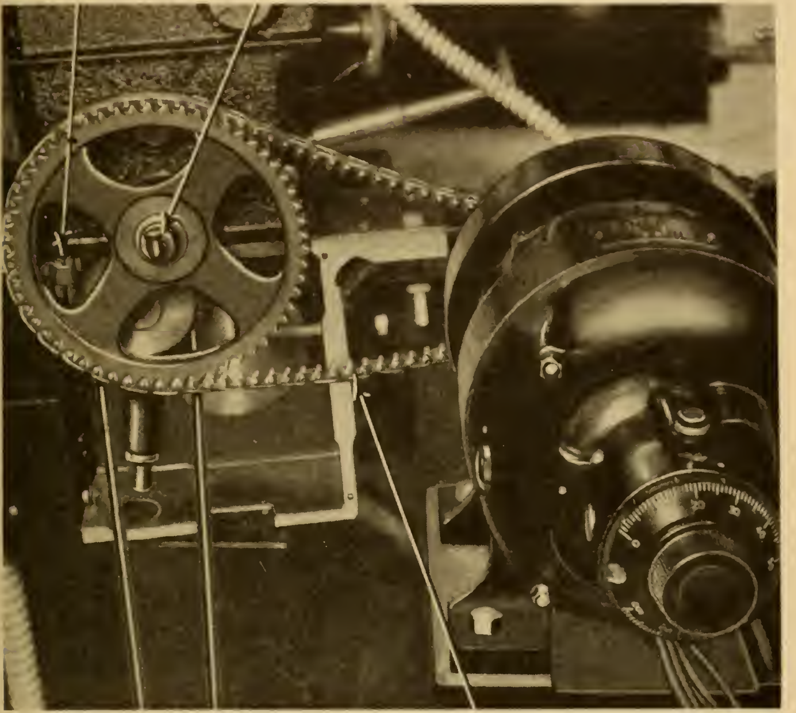


FIG. 209.—Drive using centrifugal speed control

(9) Figure 209 is a picture of a d. c. motor equipped with centrifugal speed control. Figure 210 is a schematic diagram showing the working of this apparatus, and Figure 211 is a detailed drawing of its mechanical construction.

The operation of this system is explained very clearly by Figure 210. The mechanical action is best studied in Figure 211. The centrifugal force of the motor's rotation (the same force that causes a revolving wheel to throw mud) drives the flyweights of the centrifugal device outward in opposition to the tension of a retaining spring, and compels the center on which they are pivoted to touch the adjustable contact immediately in front of it. Closing this contact (Figure 210) short-circuits a resistance in the motor field line, increasing the current to the motor field.

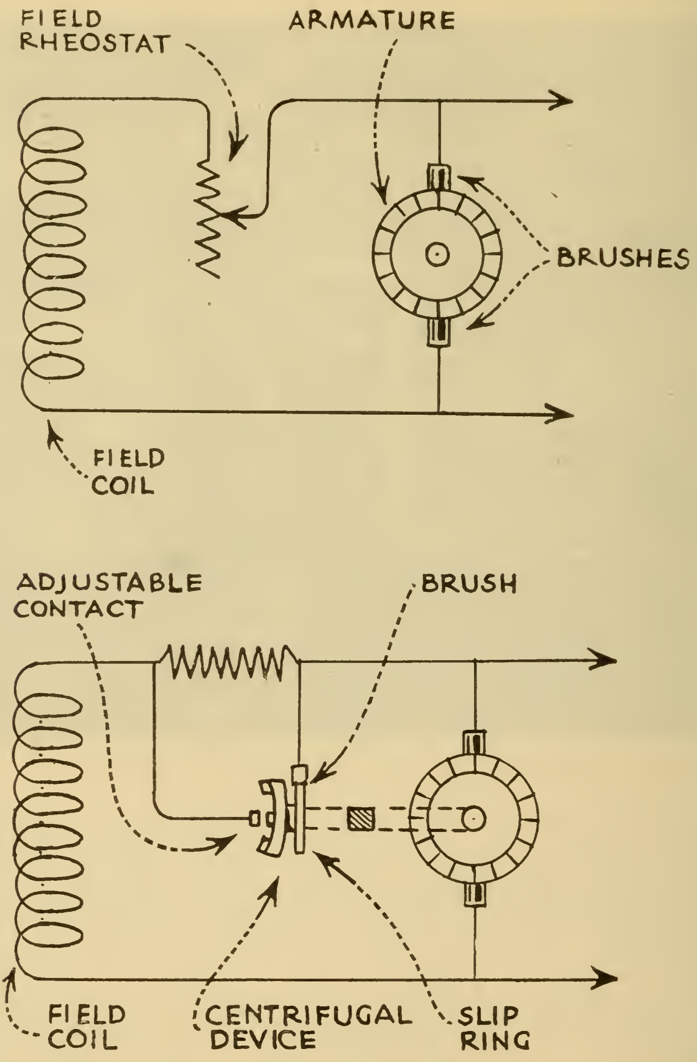


Fig. 210.—Electrical diagram of centrifugal speed control system

Any elementary book on motors will explain that when field current is increased a shunt-wound motor slows down, and vice versa. The reason, very briefly, is that a motor always acts as a generator, creating a counter-voltage in its own armature. A stronger field current increases this counter-voltage, reducing the armature current so greatly that the motor runs slower.

(10) It is high speed in the motor of Figure 210 that forces the flyweights outward and closes the centrifugal contact, thereby short-circuiting the field resistance and increasing the field current. Thus, excessive motor speed compels the motor to slow down. Conversely, when the motor speed declines, the centrifugal contact opens, cutting in the field resistance, decreasing the field current and causing the motor to speed up. The action of this contact is a continuous, chattering make-and-break. The rotating parts of the motor are too heavy to permit the motor speed to fluctuate as rapidly as the centrifugal contact opens and closes. In consequence, the motor maintains a steady, average speed, at the rate required by the setting of the adjustable contact. The radio-type dial by which this contact is adjusted is prominent in the foreground of Figure 209.

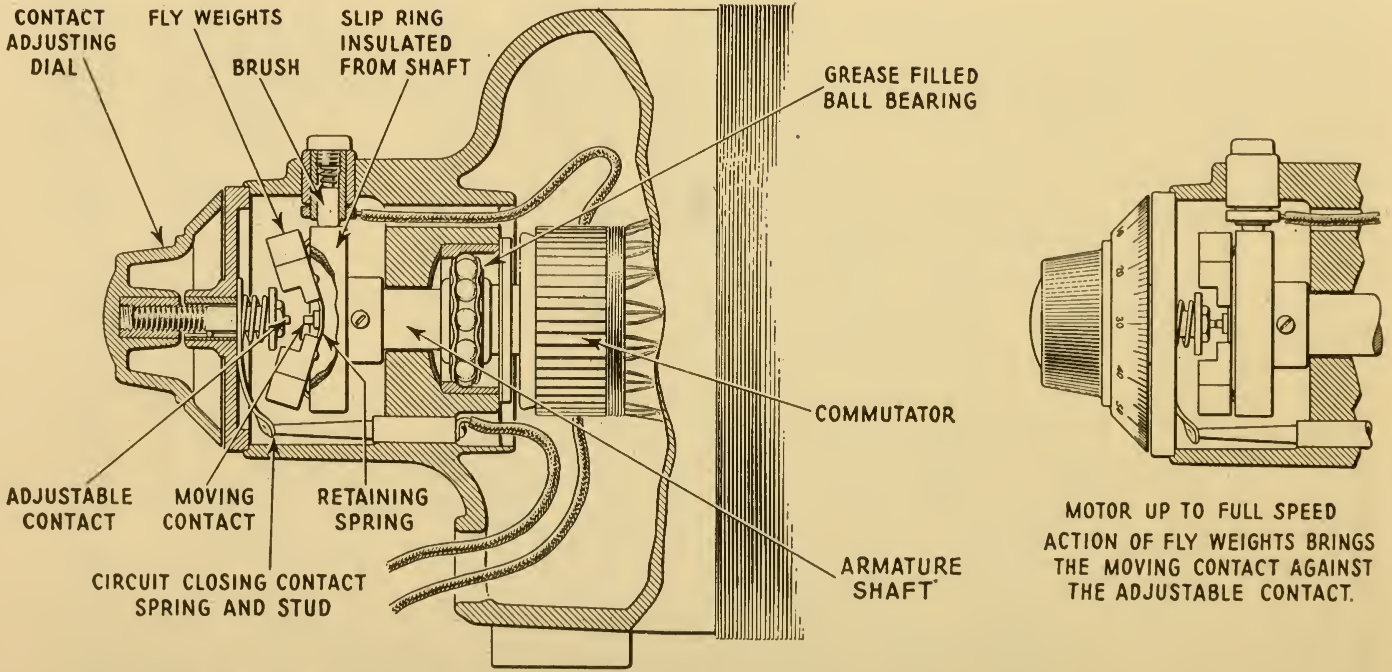
An additional three-position switch, not shown in these drawings, provides further variation of the motor field current, and therefore greater variation in speed than is attainable by the adjustable contact.

Figures 209, 210 and 211 are so plain that further discussion of this simple method of speed control seems unnecessary.

Motor Control Cabinets

(11) Five types of speed control cabinets, all produced by one manufacturer, are used to regulate projector speed. In all systems they have been superseded by the simple synchronous motor. Many, however, are still in use. The tubeless type is diagrammed in Figure 212.

(12) The dot-dash line of Figure 212 separates the motor from the control box wiring. In this arrangement



MOTOR AT REST OR AT LOW SPEED - ACTION OF THE RETAINING SPRING PULLS THE CONTACTS APART.

MOTOR UP TO FULL SPEED ACTION OF FLY WEIGHTS BRINGS THE MOVING CONTACT AGAINST THE ADJUSTABLE CONTACT.

Fig. 211.—Mechanical diagram of centrifugal speed control system

the speed is regulated primarily by the motor itself and by the induction machine (a. c. generator) mounted on the same shaft. The control cabinet apparatus merely assists in the action.

The motor of Figure 212 contains a stator consisting of the windings designated in the drawing as F-1. The speed control field is composed of windings F-2. Driving current is not led directly into the armature through the brushes. Voltage is induced in the armature by the a. c. flowing in F-1. The four short-circuited brushes shown in the drawing close the armature circuits and permit current to flow in the armature coils.

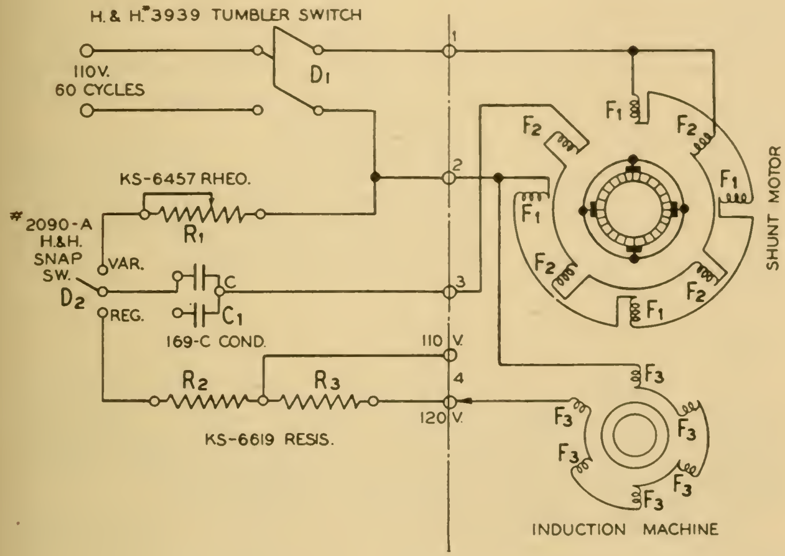


Fig 212.—Schematic circuit drawing of motor speed control cabinet without vacuum tubes

When Switch D-2 of the control cabinet (left center of the drawing) is thrown to "Regulate" the induction machine is connected in series with F-2 through R-2 and R-3, and the large condenser, C-1. If the motor runs too fast the current generated by the induction machine reinforces the current through F-2, causing the motor speed to decline. When the motor runs slow the current developed in F-3 opposes that in F-2. Additional regulation is secured by the fact that the induction machine is designed for the rated speed of 1200 R. P. M., and imposes a minimum mechanical load on the motor when it is driven at that speed.

Condenser C-1 serves to keep the current through F-2 in phase with the current induced in the armature. Without it the motor could not develop normal power. The additional condenser is sometimes connected in parallel to increase the starting torque of this motor. The contact marked "110 V.," which shorts out resistor R-3, is sometimes used for the same purpose.

When the switch D-2 is thrown to "Variable" the induction machine is open-circuited and does not function. Rheostat R-1 is then used like the field resistor of any shunt motor to vary the speed as desired.

The Circuit of Figure 213

(13) Figure 213 represents one of four types of motor control cabinets using vacuum tubes. This particular model was chosen as an example of such equipment because it is the one most widely used.

The motor is diagrammed at the extreme left. There are three stationary windings, the stator, the field and the armature. The rotating element consists of two parts, namely, the rotor and the toothed iron wheel drawn just above it. The entire arrangement, taken as a whole, may be regarded not only as a driving motor but as a motor-generator assembly consisting of one motor and two generators. One of the generators is an apparatus electrically independent of the motor, although built into the same casing. This is an inductor generator, consisting of the toothed iron wheel, the field coil and the armature coil. The other generator is the rotating element of the motor itself, the rotor. The stator is the driving field. It induces alternating current in the rotor windings, and by the magnetic reaction between the rotor field and the stator field the motor is compelled to revolve.

Let us next see how the stator winding is powered, and how the field of the inductor generator is excited.

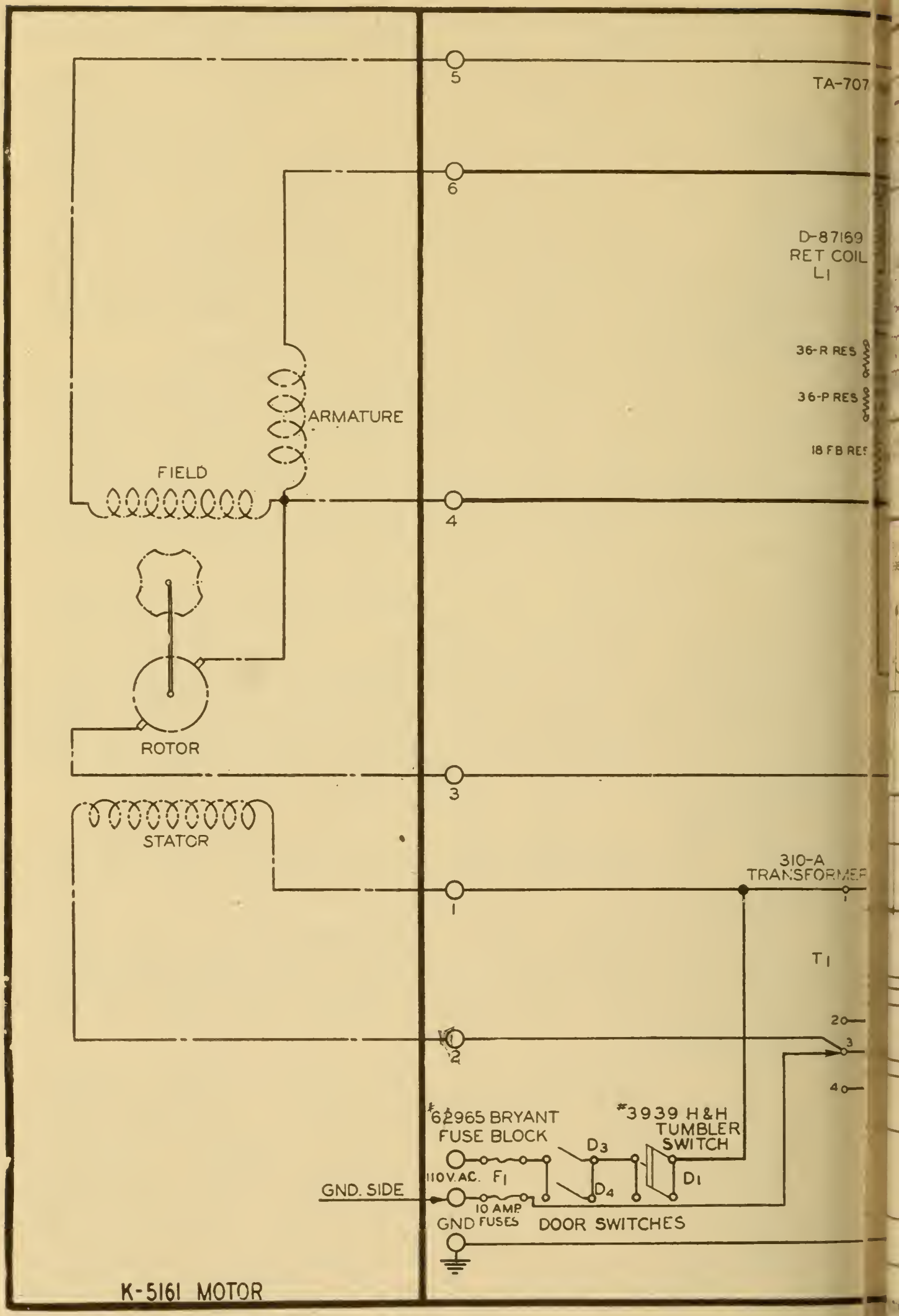
The stator is supplied with a. c. from a 110-volt line through the tumbler switch D-1 in the lower left-hand corner of the control cabinet drawing. (In physical fact this switch is located conveniently at the top of the cabinet.) The same switch also supplies line a. c. to the primary of the control cabinet's power transformer, T-1, to which we shall return in a moment. The power supply to the inductor generator cannot be fully understood until the construction of that machine is explained.

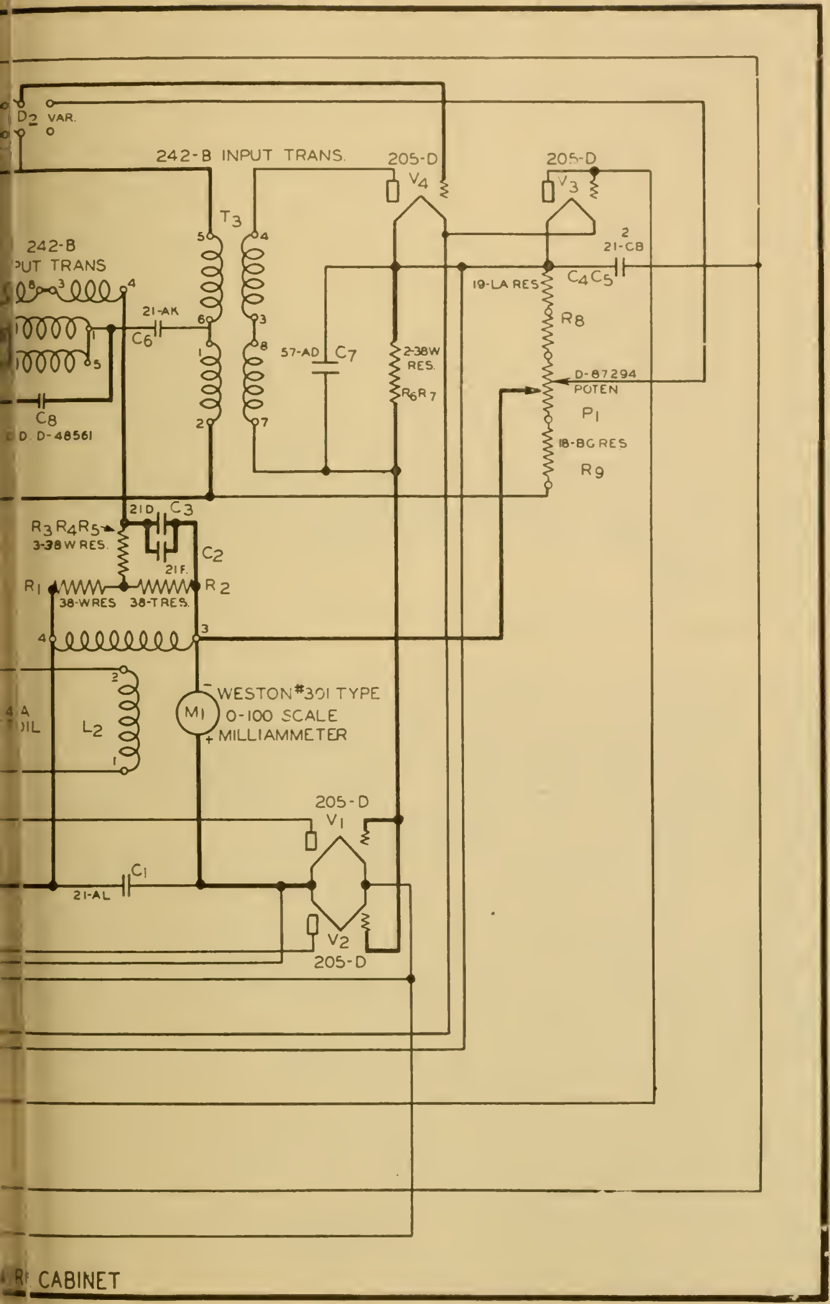
The inductor generator consists of two coils, the field and the armature, both wound on iron. The field coil is excited by direct current which is provided by a rectifier tube inside the control cabinet (tube V-3). As the iron wheel revolves with the rotor its projections pass through a gap left for that purpose in the core of the field winding. The magnetic flux of the field winding is thus made to vary in strength, and an alternating current is generated in the stationary armature. The frequency of the armature current is governed by the rapidity with which the iron teeth replace each other in the gap of the field core, and therefore by the speed of the motor. At the rated speed of 1200 r. p. m., the armature frequency is 720 cycles.

We have therefore two a. c. generators in this machine, one being the armature just mentioned, and the other the rotor.

The alternating current generated in the rotor completes its circuit through the rotor brushes and the choke coil L-2 inside the control cabinet, just left of the milliammeter.

Coil L-2 is therefore the "load" upon the rotor, exactly as an arc lamp and its ballast resistor constitute the "load" on the d. c. output of an arc supply generator. The arc generator, however, is compounded to maintain constant speed under variations of load. The motor of Figure 213 is so designed that its speed is very sensitive to changes in the rotor load. Any change in the impedance of L-2 will vary the speed of this motor.


5
TA-707
6
D-87169
RET COIL
L1
36-R RES
36-P RES
18 FB RE
ARMATURE
FIELD
4
ROTOR
3
STATOR
1
310-A
TRANSFORME
T1
2
3
4
2
*62965 BRYANT
FUSE BLOCK
*3939 H&H
TUMBLER
SWITCH
D3
D4
D1
110V.AC.
F1
GND. SIDE
10 AMP
FUSES
GND
DOOR SWITCHES
K-5161 MOTOR


D2
VAR.
242-B INPUT TRANS.
205-D
V4
205-D
V3
T3
242-B
PUT TRANS
21-AK
C6
C8
D. D-48561
57-AD
C7
2-38W RES.
R6R7
2
21-CB
C4C5
19-LA RES
R8
D-87294 POTEN
P1
18-BG RES
R9
21D
C3
R3R4R5
3-38W RES.
C2
21F.
R1
38-WRES
38-TRES.
R2
WESTON #301 TYPE
0-100 SCALE
MILLIAMMETER
M1
L2
4A
OIL
205-D
V1
C1
21-AL
V2
205-D
R. CABINET

The 720-cycle current generated in the armature acts through the circuits of this cabinet to control the inductance of L-2, and hence to control the motor speed.

The analysis of those internal circuits will unfortunately make somewhat hard reading. There is no help for that, no matter what pains are taken to make the account clear and simple. These particular vacuum tube circuits are altogether different from those we have previously traced in amplifying equipment. We will now have to encounter positive grid bias, grid-controlled rectifiers, and other strange animals. All resting, of course, on the same electrical fundamentals, but still perhaps a trifle confusing in their newness. If the reader will carefully refuse to let himself feel puzzled, remembering that if he understands the elements of electricity and of vacuum tube action he *must* be able to understand these circuits, he should find the paragraphs that follow much easier to digest.

The Impedance of Coil L-2

L-2 is wound on an iron core (not shown in the drawing). The same core also carries the coil drawn just above L-2 at right angles with it. We shall call this second winding the control coil. The two together, with their core, make up the retard coil, 144-A.

Direct current provided by the full wave rectifier (tubes V-1 and V-2) flows through the control coil, creating a magnetic field that very nearly saturates the iron core on which it is wound. The impedance of L-2 depends upon the degree of saturation of that core. A fully saturated magnetic core cannot absorb an additional field (cannot be magnetized further). If this core were completely saturated the impedance of L-2 would be comparatively small. An increase in the direct current through the control coil increases the saturation of the core, reduces the impedance of L-2, and permits the rotor to speed up. Conversely, a decrease in the direct current through the control coil raises the impedance of L-2 and compels the motor to slow down.

The 720-cycle current generated in the inductor armature therefore operates through the circuits of this cabinet to adjust the amount of direct current delivered to the control coil by the full-wave rectifier, V-1 and V-2. The next step in seeing how this is done is to study that rectifier circuit. It differs in important details from rectifiers we have seen before.

The Circuits of V-1 and V-2

The filaments of V-1 and V-2 are heated by the second secondary from the top, in power transformer,T-1. The plates are powered by the uppermost secondary of that transformer. The positive leg of the output connects to the filaments, the negative side of the circuit returning to the center-tap of the plate transformer. The output of this rectifier flows through the control coil just above L-2. There is a branch circuit through resistors R-1 and R-2, just above the control coil. Condenser C-1 (below L-2) is a filter that keeps the current through the control coil steady.

The unusual feature of this circuit lies in the grids of the two tubes. They control the current flowing through the vacuum, and therefore govern the saturation of the core of L-2 and hence the speed of the motor. Grid-controlled rectifiers of immense size are sometimes used in power houses, but are strange to projection rooms aside from these control cabinets. The grids of V-1 and V-2 carry a positive bias. Electrons are attracted to them, and there is a flow of current through the external circuits connecting grid and filament. However, the positive charge of the grid is much less than that of the plate, and only a comparatively small portion of all the electrons emitted go to the grid. The rest respond to the stronger attraction of the plate. The function of the grid is to deprive the plate of current by attracting some of the electrons. The reading of the milliammeter M-1 depends upon the positive charge of the grid, that is, upon how many electrons the grids of V-1 and V-2 are able to attract from the plates of those tubes.

GRID BIAS CIRCUITS OF V-1, V-2 AND V-3

The positive grid bias of the full-wave rectifier is obtained by a voltage drop in the field exciting current that is provided by the half-wave rectifier, V-3. The circuits of this tube are conventional, and need not detain us long. Its filament is heated (in parallel with the filament of V-4) by the third secondary of the power transformer T-1. The bottom secondary provides plate power for V-3. From the top of that plate secondary the circuit may be traced to the plate of V-3, thence to the filament of that tube, down through R-8 and R-9, left across the drawing and through the field of the induction machine, up and around the edge of the drawing to the bottom of fourth secondary of T-1. There is a voltage drop through R-8 and R-9, which as we have just seen are positive at top and negative at bottom. The grids of V-1 and V-2 connect to the top or positive side of R-8 through resistors R-6 and R-7. The filaments of V-1 and V-2 connect, through the milliammeter and the arrowhead contact, to a more negative point, lower down on R-8 or R-9. The grids of V-1 and V-2 are therefore positive with respect to the filaments of those tubes.

Now the speed of our motor is controlled by the space current through V-1 and V-2, and therefore by the bias of the grids of those tubes. Whenever that motor departs from proper speed the alternating current generated in the induction machine armature will become either more or less than 720 cycles, and an appropriate correction must be applied to the grids of V-1 and V-2. This is done by a change in the voltage drop through R-6 and R-7, which voltage drop is in series with the source of the grid bias of V-1 and V-2. Therefore, the object of the 720-cycle a. c. developed in the armature of the inductor is to control the direct current through R-6 and R-7, since the drop across these resistors depends upon the amperage flowing through them (Ohm's Law).

THE CIRCUITS OF V-4

The filament of V-4 is lit in parallel with that of V-3, the source of power being the third secondary of power transformer T-1. The plate is powered with 720-cycle a. c. provided by the secondary of transformer T-3. The primary of that transformer is excited by the 720-cycle output of the stationary armature. Current can flow in the secondary of T-3 only while the plate of V-4 is positive. Therefore the tube acts as a rectifier, and the rectified d. c. of its output completes its circuit through R-6 and R-7, where it creates a voltage drop that opposes and reduces the positive bias of the grids of V-1 and V-2. The upper, or positive end of R-6 and R-7 connects to the filaments of V-1 and V-2 as follows: upward, right, down through R-8 to the left-hand arrowhead, and thence down, left and down through the milliammeter. Condenser C-7 acts as a filter to steady the d. c. through R-6 and R-7.

The flow of space current in V-4 therefore controls the speed of our motor, and V-4 is a grid controlled half-wave rectifier.

The Grid Bias of V-4

The bias of V-4's grid can be traced backward from that grid as follows: left to switch D-2 (which we now assume is closed at "Regulate"), down and right through the secondary of the 242-B input transformer, and thence downward through R-3, R-4 and R-5 to the left-hand or negative side of R-2. Right through R-2 down, right, and up to the arrowhead touching the lower or negative side of R-8. Up through R-8 and left to the filament of V-4.

We have now progressed to the point where we see that the speed of our projector motor is controlled by the grid voltage of V-4. Before going further we may review briefly, as follows: The grid voltage of V-4 controls the space current of that tube. The space current of V-4 determines the extent of the voltage drop through R-6 and R-7. The voltage drop through R-6 and R-7 is in series with, and modifies, the bias of V-1 and V-2. (That bias is obtained from the plate circuit of V-3, through the voltage drop across R-8 and R-9.)

The bias of V-1 and V-2 rectifiers controls the space current through those tubes, and that space current controls the saturation of the core of the rotor loading coil, L-2. The saturation of the core of L-2 determines the impedance of that coil, which in turn governs the amount of electrical work the rotor must do in turning over, and hence its speed of rotation.

We must now look to see what the 720-cycle current generated in the stationary armature does to the grid bias of V-4.

WHEATSTONE BRIDGE CIRCUIT

The 720-cycle output of the armature is given two parallel paths through which to complete its circuit. One is the primary of T-3, which is divided at its center into two halves. The other path consists of the retard coil L-1 and its built-in condenser, plus the resistors R-13, R-14 and R-11. The resistors constitute the lower half of that path, and the coil with its condenser the upper half. The double primary of transformer T-2 bridges across between these two paths. This arrangement closely resembles the classical electrical circuit known as a Wheatstone Bridge.

Coil L-1 and its condenser constitute a filter circuit tuned to 720 cycles. When switch D-2 is thrown to "Regulate" and the output of the armature is precisely 720 cycles, the impedances of the two parallel paths just described are precisely equal. Equal current flows through each, and the voltage drop through the filter matches exactly the voltage drop through the upper half of T-3 primary. Under these circumstances there is no difference of potential across the bridging circuit (the primary of T-2), no current flows across the bridge, none is induced in the secondary of T-2, the grid bias of V-4 is not altered, and the motor speed does not change.

Consider conditions when this motor has just started and is coming up to speed. The armature output is less than 720 cycles. The bridge is unbalanced, current flowing through the bridging circuit. By virtue of the phase-effect of the small condenser in L-1, plus that of C-6 (which two condensers are under those circumstances in series) the current through T-2 primary is 180° out of phase with that in the primary of T-3. The drawing does not show it, but these primaries are so poled that in such case their secondary voltages will be *in phase*. The grid of V-4 will then become more positive (less negative) at the same time that the plate of V-4 becomes positive, which is the only time space current flows. Therefore:

Space current through V-4 increases.
Voltage drop through R-6 and R-7 increases.
Grid bias of V-1 and V-2 becomes less positive.
Plate current of V-1 and V-2 increases.
Saturation of the core of L-2 increases.
Impedance of L-2 declines.
Motor can speed up.

When the motor reaches a speed of 1200 r. p. m. the arms of the Wheatstone circuit are balanced and no current flows across the bridge.

If the motor speed then increases to exceed 1200 r. p. m., generating more than 720 cycles in the stationary armature, the train of events just traced is reversed. Current then crosses the bridge, but by virtue of the inductance of the coil in L-1 it would lag 90° behind the current in T-3 primary, except for the action of condenser C-6, which neutralizes this effect and keeps the current in T-2 primary in phase with that of T-3 primary. By virtue of the poling of these transformers, as just mentioned, their secondary voltages are therefore 180 degrees out of phase. Therefore the grid of V-4 becomes more negative while the plate of that tube is positive, and:

V-4 space current declines.
The drop across R-6 and R-7 becomes less.
The positive bias of V-1 and V-2 is less strongly counteracted.
Plate current of V-1 and V-2 becomes less.
Saturation of the core of L-2 declines.
Impedance of L-2 increases.
Motor slows down.

The operation of this cabinet when switch D-2 is set at "Variable" is explained later on.

There are three variations of the circuit of Figure 213. The reader who has understood the foregoing should be able to trace out their action, if he ever has occasion to deal with them, by a study of the schematic circuits pasted inside their covers.

It is the d. c. system that differs most from that of Figure 213. The 720-cycle alternator is essentially the same, but the motor is a d. c. compound-wound machine, with an additional regulating field. There is no rotor output and no coil L-2. The output of the full-wave grid-controlled rectifier that corresponds to V-1 and V-2 of Figure 213 simply flows through the regulating field of the d. c. motor. The arrangement is therefore much simpler than that which we have just studied.

The action of these cabinets governs motor speed with extreme accuracy. In Figure 213 condensers C-1, C-2, C-3, C-4, C-5 and C-7 all act as steadying influences to smooth rough rectified d. c., or to prevent sudden surges in a. c. lines, and thereby counteract the least tendency toward "hunting" in the motor action. (14) "Hunting" is a small variation in motor speed which creates flutter in the sound when it occurs rapidly, or wows if the variation is more gradual. Thus in addition to acting as speed controls these boxes perform, in a sense, the function of flywheels.

DRIVE TRANSMISSION

(15) After the motor is running perfectly, at precisely proper speed and with little or no hunting, it is still necessary to apply the mechanical power created to moving celluloid film or rotating a disc turntable. This is done through the drive transmission.

Transmission methods vary enormously. There are more methods than there are makes of sound systems, since most manufacturers have or have had two or three at least, and perhaps a dozen. However, the action of a mechanical transmission system is not invisible like that of an electric circuit. The projectionist can always see and touch the gears or pulleys of any drive he may ever have to do with, and determine by easy personal observation exactly how it works.

(16) A good transmission system will be noiseless in operation, long-wearing, easy to lubricate and simple to repair. But the first thing required of it is that it shall impart faultlessly smooth motion to the drive sprockets of a projector or to the platter of a disc turntable. The transmission must add no irregularities to the motion it receives from the motor. On the contrary, transmission systems commonly include (17) damping devices, or mechanical filters, to counteract even slight unsteadiness.

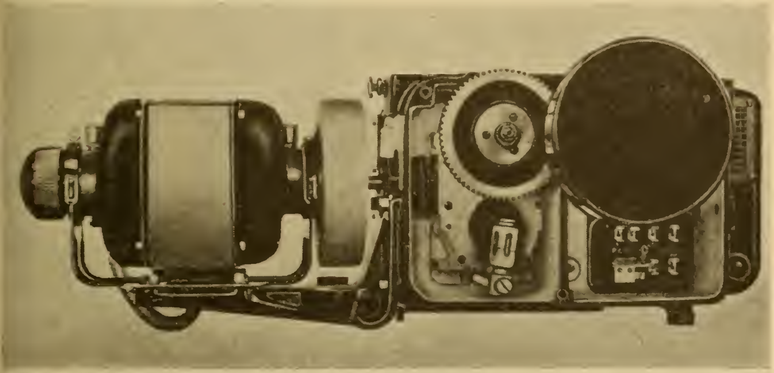


Figure 214

The basis of almost all damping devices is the ordinary flywheel, which is simply a heavy object undergoing rotary motion. To cause any object to increase or decrease its rate of motion, force must be applied, and the heavier the object the greater the force needed. Small changes in motor driving force, or in the mechanical resistance offered by the load, will (if the flywheel is heavy enough) have practically zero effect on its rate of rotation. On the other hand, however, the flywheel cannot be made too heavy in practice because it must be brought up to speed quickly (for changeover) by a motor of reasonable size. The usual arrangement is one in which a moderately heavy flywheel is assisted by other devices.

A flywheel on the motor shaft, moreover, steadies the drive sprockets only; worn teeth or oversize sprocket holes may still permit flutter in the motion of the film itself. In the now very popular "rotary stabilizer" or "kinetic scanner" type of damping device, the action of a second flywheel, independent of the one on the motor shaft, is applied not to the sprockets, but to the film. Since the contact is not direct, but through a frictional or clutch arrangement (see Page 571) this second flywheel can take its time about coming up to speed.

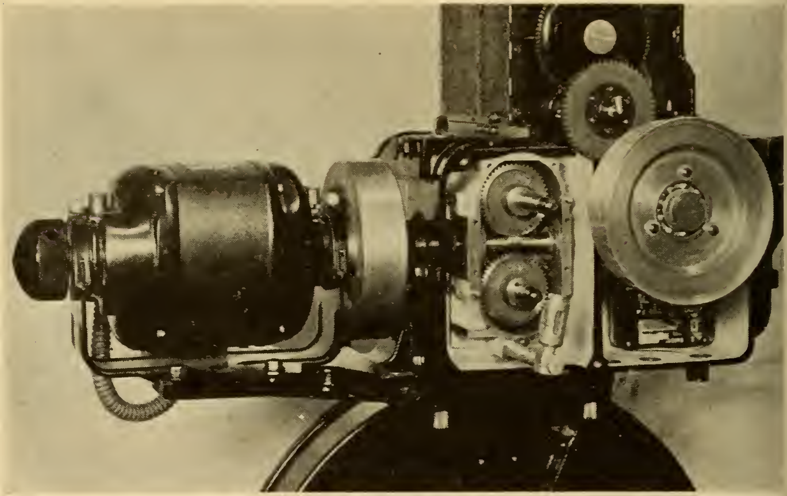


FIGURE 215

Figures 214 and 215 show the drive side of the Simplex Four-Star sound head in two successive stages of dismantling which reveal the internal arrangements.

The knob at the extreme left of Fig. 214 is used to turn the mechanism by hand. To the right of it is the drive motor and motor flywheel. Next right, half in and half out of the sound head casing, is the black motor shaft coupling. To the right of this is the drive gear through which power is transmitted to the projector. A pulley on the inner side of this gear carries the belt that drives the lower magazine takeup. Below the gear is an oil well with indicating windows. The large black circle at upper right is the casing of the rotary stabilizer mechanism referred to just below. Under this is the terminal board to which is connected the coaxial cable from Fig. 200 as well as wires carrying voltages for the photo-electric cell and the exciter lamp. The way in which power is transmitted to the large gear wheel of Fig. 214 can be seen in Fig. 215. The motor shaft is equipped with a worm which meshes with gears above and below. The shaft of the upper of these two gears carries the large gear wheel of Fig. 214. In addition, these two gears of Fig. 215 are shafted to the two sound sprockets at the operating side of the head.

The internal arrangements of the rotary stabilizer are also shown. Inside the ball race is the end of the shaft of the rotary stabilizer drum or cylinder. That drum is driven by the moving film. In turn it drives the flywheel (the large disc surrounding the ball-race, in which three machine screws are mounted). This flywheel is driven only by frictional contact *through a film of oil,* and in turn steadies the drum shaft rotation through the same slight frictional contact. The result is remarkable steadiness in the rotation of the drum shaft, which in turn is imparted to the film. (The thin outer rim of the rotary stabilizer assembly is physically united with the drum shaft and rotates with it. The oil film mentioned lies between the flywheel and this outer casing.)

Troubles and Care of Motors

(18) The care of motors is discussed in greater detail elsewhere. Here we are concerned only with special items of attention needed by projector drive motors, which amount to little more than exceptional precaution in matters of lubrication and commutator condition, in order to insure that the motor not only runs well, but that its motion is steady and without vibration.

One other matter of exceptional importance in the case of projector drive motors is that of starting torque.

Starting must be rapid enough for a smooth changeover but not so abrupt that it may damage either the film or the transmission system. In the case of some projector drive motors the starting torque can be varied by shifting the position of the brushes on the commutator. This is true, for example, of the motor shown in Figure 212. In all such matters reliance must be placed on manufacturer's instructions; details vary widely.

The same is true of lubrication, both of motors and of transmission systems. The amount of lubricant, type of lubricant and frequency of attention needed by every oil-hole and grease cup in every motor and transmission system now in use cannot be specified in a book like this. In every case manufacturer's instructions are easily ascertained, and should be followed conscientiously.

Where the projector drive motor is a single-phase machine with a separate starter winding the brushes and commutator of that winding, as well as the flyweights that open its circuit when the motor comes up to speed, need very close attention as to cleanliness and proper lubrication.

TROUBLES AND CARE OF SPEED CONTROLS

(19) The centrifugal speed control of Figures 209, 210 and 211 is mechanically similar to the arrangements for supplying current temporarily to the starter winding of a single-phase motor, but under greater strain since it remains in continuous action as long as the motor runs. Cleanliness, especially to provide free motion for the flyweights and to prevent sparking at the centrifugal contact, are vitally important.

The motor control cabinet of Figure 212 needs no attention and gives very little trouble. Any electrical difficulty that may develop is readily found with a voltmeter, since the cabinet contains very few pieces of apparatus and the circuits are simple.

When operating trouble is experienced in installations that use motor control cabinets, the cabinets should be interchanged at the first opportunity. This will indicate definitely whether the difficulty is in the cabinet or the motor, and so simplify the work of running it down.

Vacuum tube control boxes are not very troublesome. but faults that may develop in them are comparatively hard to find because of the number of circuits involved, and their interaction upon each other. In most cases, when difficulty is experienced with these cabinets the "Regulate-Variable" switch they all contain can be thrown to "Variable" and the show run with reasonable satisfaction by manual speed control. In Figure 213 this switch (D-2) open-circuits the path through the 720-cycle tuned filter, L-1, and also open-circuits the secondary of T-2. This change does not affect any of the other circuits, it merely destroys the automatic control of the grid bias of V-4. That bias is then controlled manually by moving the arrowhead at the right-hand side of R-8 and R-9 (which arrowhead, as the drawing shows, is out-of-circuit and meaningless when D-2 is set at "Regulate.") A potentiometer knob mounted on the top of the cabinet makes shifting this arrowhead a simple matter in practice.

If the motor speed responds normally to operation of the variable speed control potentiometer, that is evidence that the difficulty experienced in automatic operation is probably in the filter circuit. If variable operation is unsatisfactory the next step may be to change the tubes, beginning with V-4 as the most sensitive. The milliammeter reading is a helpful indication of the behavior of V-1 and V-2, and the presence or absence of grounds or short-circuits in their output. Beyond this point trouble is traced by voltmeter tests of the various parts and circuits. The manufacturer of these cabinets has drawn up guide charts that would fill many pages of this book, for use of their service engineers, which charts explain what troubles may be indicated by various voltmeter tests. The projectionist will probably find it quite as simple to compare the results of voltmeter tests through a faulty cabinet with those found when the identical test is repeated on the good one. The fact that there are always two of these cabinets, and two drive motors, and that a faulty instrument can be compared in detail with one in good working order, is the best help any man could have or ask in tracing trouble through these devices.

Care of Drive Transmission

(20) The transmission system needs proper, specified lubrication, attention to the tension of its belts or chains —and watching. Watch for evidences of wear or strain that may cause a breakdown, such as worn-down sprocket teeth or a frayed belt. Watch particularly for evidences of vibration or other irregular action. Flutter and even wows are often difficult for the projectionist to hear in the monitor, above the noise of his projector.

Wherever rubber is used, for coupling or damping (as in Figure 215, for example) watch the condition of that rubber. And be careful of the rubber in lubricating the equipment. Rubber is injured by oil.

Details of the care required by any individual transmission system (lubrication, etc.) may be obtained from its manufacturer,* and should be followed exactly.

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* One tiny, overlooked flaw in the transmission can bring motor, transmission, sound gears and projector head to a sudden, jarring stop, and do a thousand dollars worth of damage. Therefore, give scrupulous obedience to manufacturer's instructions with respect to lubrication and care of your own transmission system, and—watch it.

CONTROL TRACKS AND STEREOPHONIC SOUND

Practical Questions

(For answer to each question see statement of corresponding number in Chapter XXIV)

1. State two recognized handicaps of conventional sound reproduction.
2. What limits the range of volume that can be recorded on a conventional soundtrack?
3. Name one way in which soundtrack volume limitations could be overcome.
4. How else can those limitations be overcome?
5. How can a control track be used to govern sound volume?
6. How can a control track be used to create the illusion that the source of sound is moving from one place to another?
7. Where are control tracks located?
8. Describe a control track relying on sprocket hole frequency.
9. Outline a sound system using a sprocket hole frequency control track.
10. What effects can be obtained with the track and system of Questions 8 and 9?
11. Describe a control track located in the sprocket hole region of the film, but not operating on sprocket hole frequency.
12. Outline a sound system utilizing such a track.
13. What effects can be obtained with the track and system of Questions 11 and 12?
14. Describe a control film containing both sound tracks and control track.
15. Outline a sound system utilizing such a film.
16. What effects can be obtained with the films and systems of Questions 14 and 15?
17. Do control track-stereophonic sound systems present the pro jectionist with exceptionally new problems of operation, maintenance or repair?

CHAPTER XXIV

CONTROL TRACKS AND STEREOPHONIC SOUND

(1) Conventional sound reproduction as heretofore described is subject to two recognized handicaps. One relates to an inherent limitation in the range of volume available, which is less than the range of volume of real sounds as ordinarily heard, thus impairing the realism of motion picture presentations. The second relates to the fact that the apparent sources of sound, as represented on the motion picture screen, move about, or leave the screen to right or left; while the real source of the sound, the loudspeaker, occupies a fixed position, and cannot move about in keeping with the motion of the screen image. Again, realism is impaired.

(2) With reference to the volume range that can be recorded on a soundtrack, it is unfortunately true that various noises, system noises, tube noises, and so on, prevent effective recording and reproduction of any sound weaker than 25 decibels below the maximum volume the soundtrack will take. It does not matter how much amplification the theatre system has—at any single setting of the volume control the loudest sound, with ordinary tracks, will be only 25 db louder than the weakest sound. The difference is not enough for true realism.

(3) This limitation could be overcome by sending a cue sheet with each reel of film—printed instructions to the projectionist to raise the volume control so and so much at certain points in the picture. In this way, if the theatre system possessed enough reserve amplification, a volume range much greater than 25 db could be realized. Cue sheets, however, were tried in the early days of sound pictures, and resulted in more confusion than anything else.

(4) Control track sound substitutes an automatic

mechanism for the clumsy cue sheet. It effects automatic changes in the amplification of the theatre system, and thus achieves volume ranges of from 75 to 100 db although there is only a 25 db range in the soundtrack.

(5) The basis of such automatic volume control is a control track—a second soundtrack, recorded on film—which carries control signals, not sound. These control signals take the form of sound frequencies which operate through a second and independent photoelectric cell. The output of that second photoelectric cell is amplified separately from the sound. It is then rectified—converted to d.c. The d.c. thus obtained is filtered and applied to the grid of one of the tubes of the sound amplifier, modifying the grid bias of that tube, and hence increasing or decreasing its amplification. Thus the control track governs the amount of amplification of the theatre's sound system, in accordance with the degree of volume desired by the studio that made the film.

(6) The control track also can be used to create the illusion that the source of sound is moving in accordance with the motion of the apparent source on the screen. For in control track-stereophonic sound systems there is more than one bank of speakers behind the screen, and there is more than one set of amplifiers. By changing the amplification in the different sets of amplifiers, the control track can cause the volume of sound to increase in the left-hand bank of speakers while it declines in the right-hand bank of speakers, thus creating the illusion that the source of sound has moved to the left.

(7) The control track may be located in the sprocket hole region of the film; different types of track have been designed for such location. It may be a very narrow track placed between the soundtrack proper and the picture. Or it may be located, along with the soundtracks, on another film altogether—a control film without pictures, which is operated through a separate soundhead in synchronism with the regular film.

(8) Fig. 216 depicts a sprocket-hole type of control track, and the sound system through which it operates. The track is shown at the right, but the drawing does

not convey all the details. The area surrounding the sprocket holes is made black—opaque—except for one clear, transparent section which is shown at maximum width toward the top of the sound film in Fig. 216, and at minimum width toward the bottom of that film. Where this region of the film is entirely opaque the control track photocell receives exciting light only while a sprocket hole is passing. It thus produces a 96-cycle output of maximum intensity. Where (as toward the top of the film in Fig. 216) the region between sprocket holes is partly transparent, the contrast in illumination of the photocell which accompanies the passage of a sprocket hole is less extreme. Hence the 96-cycle output of the cell is weaker. When this output is weakest it does not influence the amplification of the sound system at all. When the 96-cycle control output is at maximum strength, it produces maximum increase in the sound system's amplification.

(9) In cooperation with the sound system shown in the "block schematic" that constitutes the left-hand portion of Fig. 216, the control track effects some illusion of stereophonic sound. It will be noted, in that schematic,

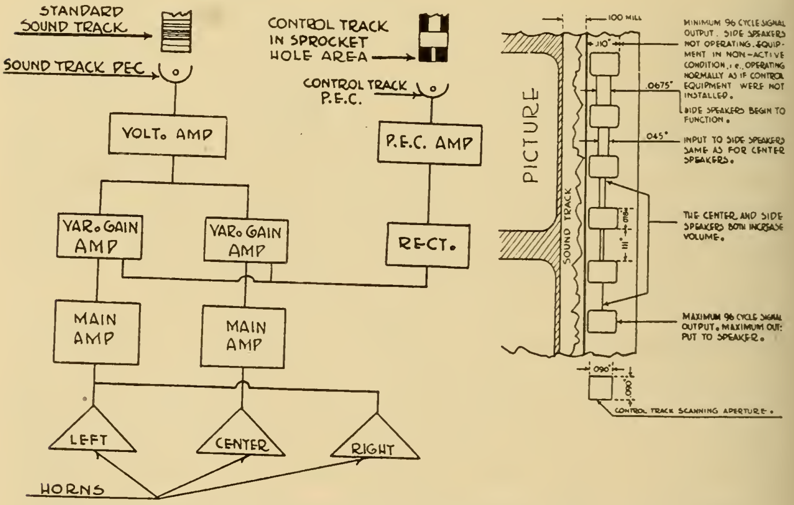
STANDARD SOUND TRACK
SOUND TRACK PEC
CONTROL TRACK IN SPROCKET HOLE AREA
CONTROL TRACK P.E.C.
VOLT. AMP
P.E.C. AMP
VAR. GAIN AMP
VAR. GAIN AMP
RECT.
MAIN AMP
MAIN AMP
LEFT
CENTER
RIGHT
HORNS
PICTURE
SOUND TRACK
100 MILL
.110"
.0675"
.045"
.0784
.111"
.090"
.090"
MINIMUM 96 CYCLE SIGNAL OUTPUT. SIDE SPEAKERS NOT OPERATING. EQUIPMENT IN NON-ACTIVE CONDITION, i.e., OPERATING NORMALLY AS IF CONTROL EQUIPMENT WERE NOT INSTALLED.
SIDE SPEAKERS BEGIN TO FUNCTION.
INPUT TO SIDE SPEAKERS SAME AS FOR CENTER SPEAKERS.
THE CENTER AND SIDE SPEAKERS BOTH INCREASE VOLUME.
MAXIMUM 96 CYCLE SIGNAL OUTPUT. MAXIMUM OUTPUT TO SPEAKER.
CONTROL TRACK SCANNING APERTURE.

FIG. 216.—Schematic diagrams of "Vitasound" system and tracks

that the output of the ordinary soundtrack is divided between two banks of amplifiers, which in turn drive three banks of loudspeakers. One amplifier drives the center bank of speakers; the other amplifier drives the right and left wing speakers. The rectified 96-cycle output of the control track photocell is applied equally to both banks of amplifiers; but the grid bias of the tube to which that output is applied is not the same in both amplifiers. It is so adjusted that when the control voltage is at minimum (maximum transparency between sprocket holes) there is no effect at all. Under these conditions the wing speakers are silent. As the control voltage increases (decreasing transparency between sprocket holes) the wing speakers begin to play; at maximum control voltage all three sets of speakers are working at their maximum volume.

(10) The stereophonic effect of this system is limited to an apparent increase in the width of the source of sound; but even this small difference is very impressive when a full orchestra replaces a soloist on the screen, and in similar conditions. The sound acquires a marked increase in depth and "presence," and the increase in volume range over that of ordinary reproduction adds to the dramatic value of the results.

(11) Fig. 217 presents a more elaborate system. The control track is located in the sprocket hole region, but in this case it consists of a variable density recording of three different control frequencies. In reproduction the 96-cycle frequency unavoidably produced by the sprocket holes is filtered off and discarded, and the three control frequencies are further separated from each other by frequency filters. Each then is separately amplified and rectified to d.c.; and each controls the amplification of one of three separate sets of sound amplifiers.

(12) There are two soundtracks (each half the normal width) which occupy the usual soundtrack position on the film. Each plays into its own half of a dual photocell. Thus there are in this system, in effect, three photocells; one for the control track, and one double cell for the two soundtracks. One of the soundtracks actuates the

central bank of loudspeakers, the other drives (through two other amplifiers) the two wing speaker banks.

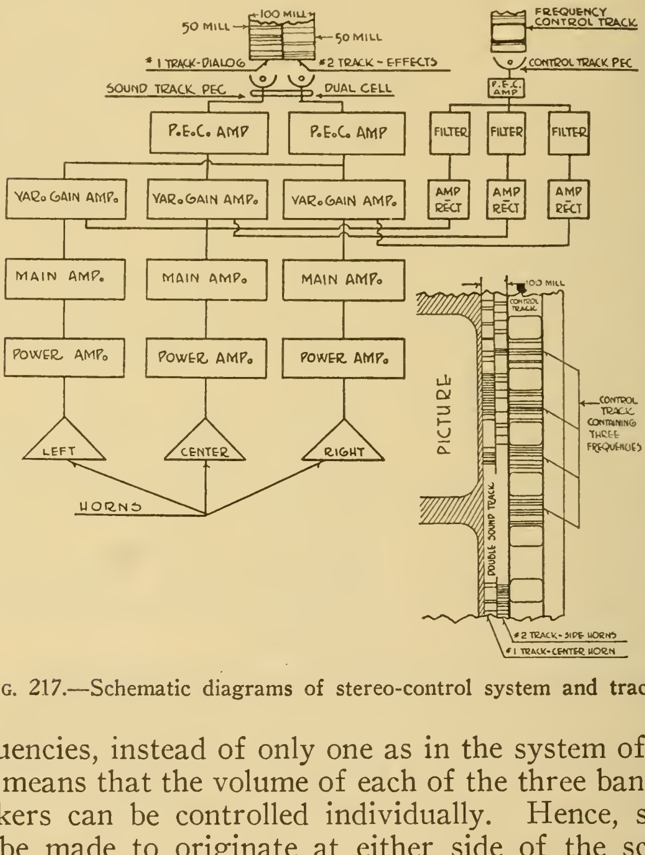

FIG. 217.—Schematic diagrams of stereo-control system and tracks

(13) The fact that there are three separate control frequencies, instead of only one as in the system of Fig 216, means that the volume of each of the three banks of speakers can be controlled individually. Hence, sound can be made to originate at either side of the screen, and move across the screen in either direction. The system falls short of perfect stereophonic results only in that the two wing speaker banks derive their sound from the same soundtrack, and therefore cannot be made to reproduce two different sounds simultaneously. The system has all the advantages of increased volume range.

(14) More elaborate and picturesque results are obtainable with the use of a control film instead of a control track. Such a film is depicted in Fig. 218. It is a normal-width, 35 mm film, but carries no pictures, only

four tracks, which, being push-pull (Fig. 167-A) look like eight separate tracks. Three of these push-pull tracks are soundtracks. The fourth is a push-pull control track.

(15) The film of Fig. 218 is operated in a separate soundhead. That is, a soundhead, drive motor, and upper and lower magazines, are mounted on a pedestal without either projector mechanism or lamphouse. Simultaneously a normal film is run in a normal projector. The motor driving the normal film and the motor driving the control film are electrically interlocked to assure synchronism. The special soundhead has four photocells, one for each of the four push-pull tracks. The control track, as in the case of the control track of Fig. 217, embodies a recording of three control frequencies. But whereas, in Fig. 217, both of the side banks of speakers reproduce the same sound (perhaps at different volume, but still the same sound) the system of Fig. 218 offers three different soundtracks playing through three different sets of amplifiers and three different sets of loudspeakers, with automatic control of the volume from each.

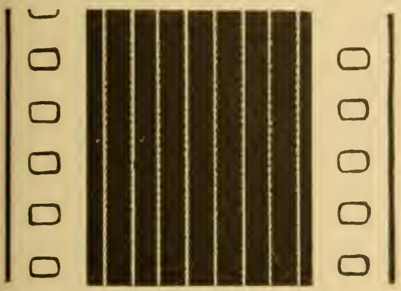

Fig. 218.—Drawn representation of stereo-control sound film (much enlarged)

(16) Full stereophonic effect is obtainable with the system of Fig. 218, and of course a very wide volume range. In addition, this system can be used with supplementary loudspeakers placed about and in the rear of the auditorium. These auditorium speakers are electrically substituted for the two wing banks of speakers; and although this is not done automatically, but by the projectionists operating a switch according to cue, highly impressive illusions are produced. The source of sound can be made to advance from the screen into the auditorium, and even to move around the auditorium. The

audience may find itself seated in the midst of multiple sources of sound.

(17) The equipments of Figures 216, 217 and 218 involve no new or radical principles, previously unknown to projectionists. They constitute essentially elaborations of conventional sound apparatus. They are somewhat more complicated to operate, to maintain and to repair, but they present no remarkably new problems in any of those connections. The projectionist who is thoroughly familiar with conventional sound equipment, and thoroughly competent to deal with it, takes these more elaborate systems in his stride; they are not strikingly puzzling nor strange.

THE OPERATION OF SOUND EQUIPMENT

Practical Questions

(For answer to each question see statement of corresponding number in Chapter XXV)

1. How can a new projectionist obtain information about the details of strange equipment?
2. What detailed information is necessary before equipment can be operated with safety?
3. Why is it necessary to understand the details of the projection room wiring?
4. Why must projection room wiring be charted and tagged?
5. What are inspection forms, and what is their value?
6. What should the projectionist do with regard to inspection forms?

Operation Routine Before Starting the Show, page 591

7. What routine is necessary before starting a show, and why?
8. What inspection is usual before starting a show?

Operation Routine During the Show, page 592

9. What routine is followed in starting the show?
10. How far is the projectionist responsible for maintaining proper sound volume?
11. How far is the projectionist responsible for maintaining proper sound quality?
12. What is one of the most important things in sound projection?
13. How does poor sound detract from box office receipts?
14. Whose is the fault where poor sound prevails?
15. What is, in most theatres, the only reliable method of monitoring sound volume?
16. Can the box office results of monitoring be directly checked?
17. What must be qualifications of a sound "observer"?

18. What are his duties?
19. Name seven variable factors that require adjustment of volume during the show.
20. How should correct volume settings be determined?
21. Should a stipulated volume control setting be used for all conditions?

Operation Routine After the Show, page 598

22. What are the projectionists' duties after the day's show is ended?

CHAPTER XXV

OPERATION OF SOUND EQUIPMENT

(1) No matter how familiar a man may be with the principles underlying the action of sound equipment he still needs a great deal of detailed information about any projection room he enters for the first time. The type of information needed may be classed under two heads, namely, detailed instructions for operating the particular make and model of apparatus installed, and detailed knowledge of the wiring, fuse locations, etc., in that individual projection room.

Obtaining Detailed Information

Five possible sources of such information are open to the newcomer. (a) The necessary knowledge may be obtained from the projectionist previously in charge, if he is available. (b) If the theatre is one of the large number that are regularly visited by a sound service engineer, that engineer may be called in to instruct. He will be thoroughly familiar with the system and able to answer all necessary questions. (c) If the projection room equipment has been properly marked and tagged and charted, as explained in detail further on, no instruction will be necessary. Any competent projectionist will be able to run his show by referring to that information. (d) Any brother projectionist who has had experience with equipment of the same make and similar model will prove helpful. (e) Lastly, even if the apparatus has not been properly marked, search of the projection room should turn up the operating instructions that every manufacturer of sound equipment furnishes to his customers.

In the very rare cases where all these aids are missing a competent projectionist will still be able to study out the equipment for himself. He knows what it is intended to do, and the principles on which it works. In addition to having that knowledge he needs chiefly reasonable time, and willingness to be patient and careful. Switches should not be thrown in blindly, "to see what will happen." A switch on strange equipment should not be thrown in until prolonged examination of its position and connecting wires has given the projectionist a very good idea of what that switch is for and what it does. The first few switches are the hardest to figure out, and the most dangerous to try. Once a few of the controls have been mastered, understanding the rest will prove comparatively simple. Similarly, the projector motor should not be started until one is certain the film has been threaded correctly. When you think you have got it right take a little more time to look at it carefully and figure out every detail of what will happen when those sprockets start to revolve. And so on. All of which is only common sense.

Fortunately, even though a competent and careful projectionist can master strange equipment without help, the situation seldom arises. A man without experience of the type of apparatus installed is not likely to be assigned or permitted to take charge of a one-man projection room unless a sound engineer or the projectionist previously in charge is available as instructor.

Printed information, it should be noted, is almost always open to the suspicion of not applying with complete accuracy to any individual projection room. This point has been discussed on Pages 527-528 and will be referred to again on Page 589; it cannot be stressed too often. The hardest troubleshooting in the world is the kind that is done with an inaccurate diagram! Data relating to equipment which is received in the same shipment with the equipment itself can in general be trusted. For everything else, including installation wiring, re-check in advance of trouble is highly desirable. It can be done a bit at a time, and constitutes an ideal introduction to one's equipment.

Operating Information

(2) To operate a sound system the projectionist needs the following information:

(a) Switches. He must know the location of all necessary switches, and the order in which they are to be turned on in the morning and off at night. He must know the peculiarities of those switches. For example, many amplifiers, large ones, particularly, use three-position control switches by means of which the filaments of tubes are heated before plate power is turned on.

(b) Threading the film. He must know how to thread the film through the projector and the sound drive, what loops to leave and how large to make them.

(c) Meter indications. He must know what every meter in the projection room should read, what condition any abnormal reading is likely to indicate, and what must be done to remedy that condition.

(d) Lubricating points. He must know what points of the equipment need lubricating, how often, and what type of lubricant to use in each.

(e) Controls. He must know where to find all current rheostats provided in the equipment, how to adjust them, and what the proper adjustment of each should be. He must know how to control volume and how to change over between projectors.

(f) Special information. Under this heading we group an almost endless number of small details, all important. How to re-focus the exciter lamps, for example. Exciting lamp focus is managed differently in different makes of apparatus. Again, how often the storage batteries need to be re-charged (if there are storage batteries) and at what current rate. Or what is the relationship between monitor volume and theatre volume, and what volume from the monitor indicates correct volume in the theatre for average conditions. There is also what may be called, for want of a better term, precautionary information. For example, to what extent does temperature rise in any part represent normal operating condition, and at what point does its increase in temperature indicate trouble?

The projectionist confronted by a strange projection room and strange equipment can, if he has to and if he knows his fundamentals, work out most of the above information for himself, taking time and being very careful not to do any damage in the process of finding things out. But it is infinitely better to secure proper advice from someone who knows, if there is any possible way to do it.

Wiring Information

(3) The work of securing information about the projection room is not nearly ended when all the foregoing have been mastered. The above details are only matters that must be known before it is possible to get the show running. Keeping it running requires further information. Details of the projection room wiring must be known thoroughly or some minor trouble like a burnt-out fuse may hold up the performance for a long time. The projectionist cannot expect to delay locating the fuse cabinet of a strange projection room until after a fuse burns out. He should know every fuse in the place, and what circuit it controls, before he threads up his first reel of film for an audience.

In addition it is necessary to understand all transmission lines, where they originate, through what connection boxes they run, and where they terminate. This information is absolutely necessary to finding trouble. Naturally, the time to gather it is before trouble has occurred, and not while an audience is waiting impatiently for repairs to be completed.

The details of projection room wiring should always be thoroughly charted. Therefore this is one type of information that will give a new projectionist no trouble if previous incumbents have done their duty. The newcomer will find a detailed chart inside every fuse cabinet, usually pasted up inside the door, showing what circuit each fuse controls and what size it should be. Spare fuses are often placed inside each fuse cabinet; if not, the fuse chart should explain where they can be found. Connection boxes are similarly charted, or if not, each wire or pair of wires is tagged. Connection terminals to amplifiers and other sound equipment are usually labelled by the manufacturer, or they are numbered, and an explanatory diagram is pasted up inside the door or cover. Where neither is the case the wires should be tagged with full information.

In some projection rooms the necessary information relating to the projection room wiring is posted in the form of the sound manufacturer's installation diagram. This should never be trusted without further investigation. Such diagrams only tell what the manufacturer wanted. The conditions existing at the time of installation may have made some departure from that standard necessary. In fact, the actual wiring may be very different from the standard. Sometimes, however, such drawings are modified with pen and ink to show departures from standards, and where this has been done they are probably trustworthy.

(4) If the incoming projectionist does not find all wires carefully tagged or charted he should ask for enough overtime to do the job, calling on the sound service engineer, if the theatre is receiving sound service, to work with him. He should do this for three reasons. First, for his own guidance to quick repairs, in time of trouble. Second, as fair play to his successor in that projection room. Third, because he may be sick or take a day off, and the relief projectionist that replaces him will need the same information.

Other information, in addition to wiring detail, should be made available. Correct meter readings, if not shown by a red line on the dial of the instrument, should be marked on the glass with a red china-marking crayon or in some other conspicuous way. "On" and "off" positions of all covered switches should be similarly marked. So should normal operating positions of rheostats and other controls. Correct battery charging current should be indicated on the charger panel, and so on.

Last, all switches and other controls should be numbered or otherwise plainly identified, and complete operating instructions describing their use in detail then drawn up and posted in a prominent place. These instructions should include everything the projectionist himself would want to know if he entered that projection room for the first time as a new man unfamiliar with its equipment. The manufacturer's information pamphlet should form the back-bone of this data, but must never be regarded as complete in itself for the reason that it does not and cannot take account of individual peculiarities.

Having taken these precautions the projectionist in charge can report sick or on vacation with a clear conscience, knowing that any competent relief man will be able to keep the show running without trouble, and will not injure the apparatus.

Inspection Forms

(5) Since all sound equipment needs both inspection and attention, written or printed routine forms are the best safeguard against accidental neglect. The routine inspection and lubrication necessary before each day's run should be covered on one such form, while others cover the necessary items of weekly, monthly and semi-annual attention. These latter forms are explained in the next section, which deals with Repair and Maintenance.

(6) If such forms are not provided by the theatre management the projectionist should draw them up for himself. They will save him worry. Merely by following a written or typewritten guide, every morning and every week, he will know that he has taken care of every last detail necessary to keep his equipment in good condition. The fact that he can put a form of this kind before his manager, if any question should arise, will prove of the greatest help to sustaining his side of the argument, and moreover gain him the respect that is always given to a conscientious man who knows his job and is willing to take the trouble to do it properly.

Wherever such forms are provided by the management (which is often the case in chain theatres) the projectionist should add to them any special items of inspection that he finds necessary or desirable in connection with his own equipment. These additional items will in some cases be temporary; for example, a gear that is usually inspected once a month may show signs of wear and need inspection once a week until it becomes bad enough to be replaced. Or they may be permanent, referring to some special weaknesses peculiar to the apparatus or conditions of his own projection room. The fact that some necessary item of attention or inspection is not included on a general form intended to apply to a large number of theatres is no reason for neglecting it.

Now, assuming that the projectionist possesses or has acquired all the detailed knowledge necessary for the proper operation of the one, individual projection room for which he has accepted responsibility, and assuming further that he possesses or has provided himself with all convenient guide forms to routine inspection and operation, let us trace his daily procedure in preparing for the show, starting the show, operating it, and closing down at the end of the day.

Routine Before Starting

(7) It is common practice for the projectionist to start work from fifteen minutes to an hour before the scheduled beginning of the show. Many theatres pay for such additional time, and all will find it worthwhile to do so. Many small items of care, resulting in the aggregate not only in a better performance but in prolonging the life of equipment, cannot be attended to properly while a show is running.

(8) The procedure before the show varies from theatre to theatre, and according to the type of apparatus. In general it runs approximately as follows:

(a) Apply lubrication, according to a prepared routine that makes certain nothing is overlooked.

(b) Check condition of storage batteries (if used) and of dry cells (if used).

(c) Switch on the system, and check all meter readings.

(d) Inspect exciting light focus of both projectors, adjusting it if necessary.

(e) Make click test for sound. This test is made by removing the sound gate (if necessary) and interrupting the exciting light. Moving a pencil or a finger rapidly through the beam is the usual method. A rumbling or clicking sound will be heard in the speakers if the system is functioning. Click test of the disc reproducer is made by brushing a finger against the needle. The microphone is tested by speaking into it. These tests should be applied to both (or all three) projectors, to all disc reproducers, synchronous or non-synchronous, and to all microphones that will be used in the course of the day's show.

(f) Where there is more than one stage speaker the click test should be repeated for each speaker separately, to make sure that all are working. This last, however, is not possible in all theatres. In some the speakers cannot be switched on and off individually.

(g) In some theatres the above tests are followed by a trial run of sound, as a check upon quality.

The above list represents what is perhaps average procedure. In any individual projection room there will be other items, perhaps many others, that can and should be checked before the show is started. In this matter individual conditions are the only guide.

Routine During the Show

(9) Having completed his preliminary inspection the projectionist threads up the first two reels of the show and waits for the starting buzzer or for the scheduled starting time.

Where two projectionists are engaged they commonly check on each other's work in threading up the film. This is a routine precaution of inestimable value.

At schedule time or at a buzz from below the projectionist starts the motor of the projector that carries the first reel of the performance, switches his fader to that projector as soon as proper running speed is reached, and adjusts his volume control, if necessary, for that monitor volume which corresponds to correct volume in the auditorium.

His responsibility during the show with respect to threading, removing, inspecting, repairing and storing film is treated of in Chapter XI. His responsibility with respect to projecting a bright, clear and steady picture requires no explanation.

(10) His sound responsibility sometimes includes listening to the monitor and adjusting volume whenever necessary to compensate for inequalities in the recording, but this is poor operating practice. As explained below, volume should always be controlled by signals from the auditorium. When the monitor is used it should always be kept as low as possible, since if heard in the auditorium it sounds like echo coming from the rear wall. Even where the projectionist is solely responsible for volume the monitor is often turned off entirely, except for changeovers, during pictures in which the recording is known to be of constant level.

The projectionist observes his meters periodically, and especially often at hours when the power line voltage is subject to change, adjusting his rheostats or line voltage controls as circumstances indicate.

He follows a pre-established routine of checking his equipment during the day for evidences of excessive heating or other signs of possible trouble, paying special attention to any part that may have given indications of weakening.

(11) The projectionist is sometimes held responsible for noticing bad quality or noisy sound, but such matters should always be checked in the auditorium. Projectors in action are unavoidably noisy, and many sound troubles cannot be heard in the projection room. An observer in the auditorium must note them, and telephone the projectionist of their existence. With some troubles, misalignment of the lateral film guides, for example, the observer in the auditorium must co-operate with the projectionist via telephone if the difficulty is to be cured completely while the reel is running.

Likewise, as has been said, the projectionist in some theatres is held responsible for controlling sound volume by means of his monitor. This also is very poor practice.

Good sound is an extremely delicate matter, requiring constant attention.

(12) The one most important thing to be attained in the reproduction and projection of sound in a theatre is *naturalness*. The object is to have the theatre patron forget he is seeing a motion picture and hearing "canned" sound, and become so lost in the play that he visualizes the screen shadows as real, and the sounds as sounds from the real man, woman, instrument or whatever the seeming source may be.

This is a condition that cannot be attained if the sound be too loud, too low, or unnatural in any other way. If the sound (words for example) be hard to understand, the mind automatically seeks the reason and remembers that it is not hearing sound from an original source. Thereupon it automatically blames the theatre equipment or the projectionist or both for the destruction of its happy illusion, and there is dissatisfaction.

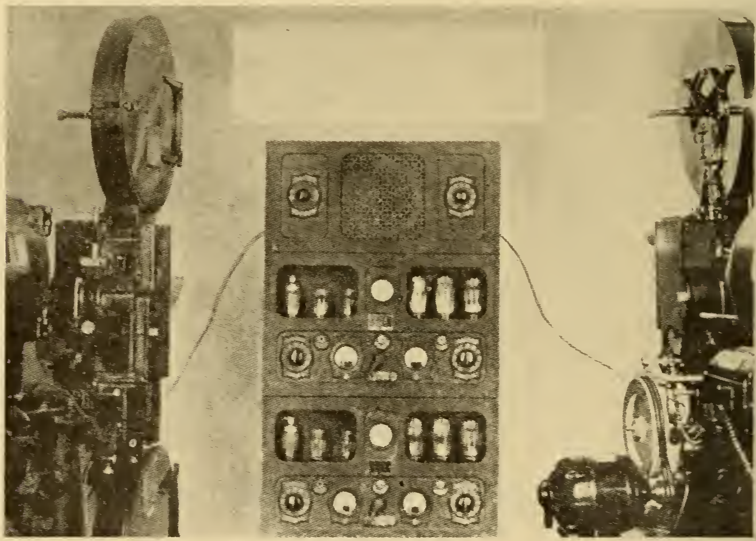

FIG. 219.—Double-channel amplifier with built-in monitor speaker in top panel. Compare with Fig. 202, page 518.

(13) In a considerable majority of our theatres ears are often obliged either to hear unnecessarily loud sound, or else are under constant strain to distinguish more than

an occasional word or sentence of the dialogue. Where either condition obtains, discriminating theatre patrons (and their number is rapidly increasing) either lose their taste for motion pictures or else seek some place of entertainment where sound projection is better managed. If there be none such available, the interval between their theatre visits lengthens very noticeably and the theatre box office suffers.

(14) Such conditions are not ordinarily due to any fault of the projectionist. The fault rests squarely on the shoulders of the management or the manager. It is due entirely to the fact that either he has not installed any system of volume control, or if he has one it fails in its purpose.

The monitor horn unfortunately cannot be made to supply a reliable guide to auditorium sound volume. It serves merely to assure that the sound equipment is operating and for the receipt of sound cues.

(15) In all except a very few theatres the only practical system of volume control under all conditions is by means of an "observer," and a bell and buzzer located preferably on the front projection room wall, between the motion picture projectors.

This bell or buzzer is controlled by a bell button located in some inconspicuous place in the rear of the auditorium, not too near an entrance. On the back of one of the aisle seats in the rear row is usually the best location.

This bell is for use by the observer, who by a prearranged signal code is enabled to advise the projectionist as to sound level.

Provided the right person is selected for the observer, and further provided he attends solely and continuously to that duty, the results will be very greatly improved and the cost of the observer unquestionably will be much more than covered by retention of patronage and new patronage attracted by excellence of the entertainment.

(16) This is, however, something that unfortunately cannot be directly checked. It is a matter upon which the manager must use common sense and his reasoning powers. His showmanship must be his guide.

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(17) No person other than one having normal hearing power can serve acceptably as observer. His hearing must be in no degree defective; also it must not be abnormally keen. He should have some sense of dramatic action and be musically inclined. These last named qualities are of very great value in the efficient control of sound volume. (18) He must not stay in one place, but pass occasionally from one part of the auditorium to another, including the balcony, and keep close watch on sound conditions in all parts of the theatre. He must be a man who has some appreciation of the importance of his position and of the value of excellence in monitoring.

(19) Many factors tend to make volume changes imperatively necessary if optimum results are to be attained.

First, there is a vast difference in volume demands as between an empty auditorium and one that is well filled.

Second, audience movement, noise in the aisles caused by patrons walking in or out.

Third, auditorium reaction to comedy or effects that produce loud laughter.

Fourth, cold weather. Audience wearing heavy clothing.

Fifth, hot weather, with consequent light clothing.

Sixth, departure of a portion of the audience, or the theatre gradually filling up.

Seventh, low recording, or some fault of the equipment that lowers volume.

These various conditions are for the most part highly variable. Only low recording, equipment fault and audience clothing are likely to create a condition lasting without appreciable variation throughout a whole show.

There are, too, atmospheric conditions that change things. A clear, cool night for example, will probably call for a lower volume setting than will a damp, warm atmosphere.

(20) During the first projection (preview if one is had) of a picture, the average volume control number should be noted for each scene thereof, and the same noted on the cue sheet (with the mental note, however,

that if it be a preview with an empty theatre the real setting with a full house will probably be one or two numbers higher.) The setting will of course be directed by the observer through his signal bell. This method gives each scene the best possible rendition.

(21) Managers should never attempt to regulate sound by stipulating a certain volume control number for all conditions, or for constant use each day a production is shown. There are too many conditions constantly demanding change in volume. A volume control position that might be quite proper for a scene today may be all wrong tomorrow for any one of several reasons.

No theatre pretending to provide high class entertainment can afford to operate even for one day without a well trained observer attending strictly to business during every moment of the show. If there be no observer, or one entrusted with other duties, while it is quite true that business may show no observable decrease or harm, a reputation for poor or unreal sound effects will always, if invisibly, be unfavorably reflected in box office receipts. The understanding manager—he who has that undefinable quality called "Showmanship"—knows this to be true and refuses to take chances on loss of business through defects that can be remedied.

Unfortunately it is a much too frequent occurrence for theatre patrons to be obliged to sit through a show where an unwise manager has made no adequate arrangements for sound monitoring. The projectionist, having nothing to guide him except a monitor speaker, which is utterly unsuitable for accurate check of volume, cannot possibly help the sound running wild, blasting the ears at times and at other times straining them to distinguish dialogue.

Although it is difficult to make some theatre managers realize the value of high class projection, the thing is always perfectly obvious to him who will take a minute to get his whole mind off the matter of saving a few cents and concentrate upon making a few dollars added box office returns.

Unquestionably, lack of adequate sound monitoring in years past has cost theatres as a whole hundreds of thousands of dollars in business loss.

Too much volume is a more common, and always a much more serious fault, than too little. Audiences will soon complain if sound is too low. But not being sound experts they don't know that the intense discomfort they experience at other times is created partly by a too savage assault upon their eardrums and partly by excessive reverberation (caused by excessive volume) which makes sound difficult to understand. All they know is that they automatically, and very often subconsciously, associate the idea of that theatre with the idea of acute discomfort.

In some cases of poor volume control the trouble has been traced to the use of the wrong man for observer. Many persons have defective hearing and don't know it. At some convenient time after hours the entire theatre staff should listen to sound and compare what they hear (especially with respect to high frequencies) when the volume is progressively lowered. This test will reveal some member of the staff as having good, average hearing (not too good). This person should either be chosen as observer, or, if his other duties prevent this, as a "standard listener" against whom all candidates for the post of observer should be tested by a similar procedure. A multiple-frequency test reel, such as the one offered by the Society of Motion Picture Engineers, provides ideal sound for this test.

ROUTINE AFTER THE SHOW

(22) Any defects in the condition or functioning of the equipment that may have been discovered during the day, either by inspection or in the course of operation, and were not completely and finally cured at the time, should be repaired before the projectionist leaves the theatre. Only very minor matters should ever be left to the pre-show routine of the following morning, and in every such case the projectionist should take care to post up a reminder for himself.

Reminders should always be posted in connection with any matter whatever that is carried over another day. If, for example, a certain part has shown indications of possibly causing trouble, and needs watching, always thumbtack a reminder to that effect on the bulletin board or on a convenient wall space.

Such reminders should of course be very complete and explicit if a relief projectionist or crew is to be on duty the day following.

In many theatres it is the practice to end the day's work by submitting a written report to the manager. It also is a common custom at the end of the day to draw up and submit to the manager a list of supplies needed. Thus if a tube burns out, for example, a new one is ordered without delay, and the theatre's stock of emergency spares never becomes depleted.

MAINTENANCE OF SOUND EQUIPMENT

Practical Questions

(For answer to each question see statement of corresponding number in Chapter XXVI)

1. What is always the first step in finding trouble of any kind?
2. What is the second?
3. If the trouble occurs during the show, what is most necessary in finding it?
4. What are the qualifications of a good trouble-shooter?
5. Why does a *good* workman never blame his tools?
6. What tools are necessary to do a proper job of trouble-shooting in sound apparatus?

Repair of Trouble, page 608

7. What is a temporary repair?
8. Why are temporary repairs necessary and valuable? When should they be avoided?
9. Is a permanent repair completed when the trouble has been entirely removed? Why not?
10. What are the requirements of a permanent repair?

Types of Trouble, page 610

11. Explain how the cause of complete loss of sound can be traced down and remedied.
12. Explain how the cause of low volume can be traced down and remedied.
13. Explain how the cause of poor quality can be traced down and remedied.
14. Explain how the cause of failure of a power supply circuit can be traced down and remedied.
15. Explain how the cause of a foreign noise can be traced down and remedied.
16. Where is the use of headphones helpful?

17. What procedure can be followed in dealing with intermittent troubles?

MAINTENANCE, PAGE 614

18. Name the two chief requirements of good maintenance.
19. What paper help is necessary to insure reliable operation?

INSPECTIONS, PAGE 614

20. What routine inspections are necessary to any sound system?
21. How can the projectionist easily provide himself with thoroughly useful inspection forms?
22. What items of attention should be included on the daily inspection forms?
23. What items of attention should be included on the weekly inspection form?
24. What items of attention should be included on the monthly inspection form?
25. What items of attention should be included on the semi-annual inspection form?
26. Does the responsibility of the projectionist end when he has completed his inspections and properly marked the forms?
27. What procedure must always accompany or follow inspection?

SOLDERING, PAGE 617

28. Why is good soldering for a power circuit poor soldering in a sound circuit?
29. What are the requirements of good soldering in sound work?

TESTING SOUND PARTS, PAGE 618

30. How can resistors be tested in the projection room?
31. How can inductances be tested in the projection room?
32. How can transformers be tested in the projection room?
33. How can condensers be tested in the projection room?
34. How can tubes be tested in the projection room?

PURCHASING, PAGE 620

35. What is good maintenance practice with respect to stocking spare parts?
36. What is good maintenance practice with respect to selecting parts and supplies?
37. What paper help is indispensable to economical maintenance?
38. What maintenance factors should be considered in the selection of a new sound system?

CHAPTER XXVI

MAINTENANCE OF SOUND EQUIPMENT

Both maintenance and trouble-shooting are treated in this section. The discussion of trouble-shooting is essentially of a general nature, and outlines principles of procedure rather than the exact steps to be followed in any given case. The latter will be found in the series of charts that follow. The charts, however, are not self-sufficient, and neither is the present discussion of principles; the two supplement each other. Both should be studied and consulted.

FINDING TROUBLE

(1) Generally, the first step in finding any kind of trouble is to find out, not what, but where it is. Until that much has been done the projectionist cannot even begin to look for its cause because he will have little or no idea of where to start.

How any particular kind of trouble may be traced down to some one piece of apparatus or some one circuit is explained further on, and detailed in the charts.

(2) When the difficulty has been so far isolated that the projectionist is able to say with certainty that it lies in this amplifier or that control cabinet or whatever the apparatus may be, the exact fault is hunted inside that apparatus. How to find troubles inside each component part of a sound installation has already been indicated, and again, the charts give full details.

(3) When trouble occurs during the course of a show speed in finding it and repairing it is of the greatest importance. Every minute of delay in restoring the performance may mean another dollar or another ten dollars in box office refunds (depending upon the class of theatre) and just that much more patron dissatisfaction. Therefore the projectionist confronted with unexpected

trouble must know exactly what to do and precisely how to go about doing it, without having to stop for prolonged reflection. The competent projectionist will be mentally prepared for any type of difficulty he can possibly anticipate, and when it occurs go about restoring his show without waste of time.

(4) Since time is of such vital importance in repairing trouble, the first qualification of a good trouble-shooter is that he keep cool in emergency. If he knows his equipment thoroughly, in principle and in detail, he will find it easy to keep cool and to work fast and systematically. If he is doubtful and uncertain of his knowledge of his business he will probably become flustered, and then nothing but undeserved good luck can help him.

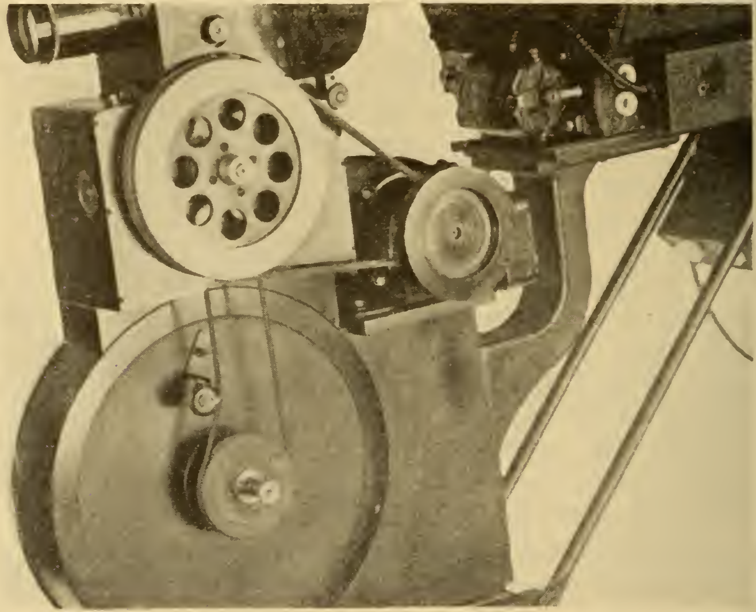

FIG. 220.—Belt-driven sound-head

The qualifications of a good trouble-shooter are therefore coolness, full and detailed knowledge of his business, and the self-confidence that only such knowledge can give.

One other qualification is the possession of proper tools for his work. (5) A good workman never blames his tools because he knows the value of obtaining good ones. He knows that having the proper tools and keeping them in good shape is the only condition on which he can do good work. The projectionist is entitled to demand of the theatre the test equipment necessary to find trouble quickly and accurately. If such equipment is not supplied a broken wire may take two hours to find or sound quality continue consistently bad.

Instruments Used in Trouble-Shooting

(6) Perhaps the most necessary single instrument for trouble-shooting is a pair of good, high-resistance headphones. Next to these, and practically as indispensable, is a multiple-range combination voltmeter-milliammeter of good quality and high internal resistance.

Do not buy either cheap, low-resistance phones or cheap, low-resistance meters. They are not only useless for sound work, but may prove seriously dangerous to the apparatus because they pass too much current. Buy such equipment from a reliable source only and explain the purpose for which it is to be used.

A rectifier-type a. c. voltmeter and ammeter is likewise extremely useful. The same instrument can be used as an output or volume indicator. The supplier will provide a correction chart by means of which voltage readings of this meter can be converted into decibels, the units in which sound volume is commonly measured. Sound power can be expressed in either decibels or watts. (The decibel is usually chosen because it is the more convenient unit. In the same way water can be measured in quarts or in ounces, but it is generally more convenient to figure in quarts.)

The theatre should by all means have a reel, or at least loops, of test film. The reel is preferable, and lasts longer. Either reel or loops should contain sound recording of excellent quality for testing the system, and in addition pure-tone recordings of a number of frequencies. If disc is of importance in the theatre records of high quality recording and frequency test records should also be available.

The high-quality sound recording serves to check the equipment not only for generally good response but also for such particular troubles as flutter. Piano recordings show up flutter very plainly, and are often used for this purpose. The frequency recordings are used with an output meter or volume indicator. For this purpose it is best to use a reel containing a number of frequencies, all recorded at the same level. The volume control is not changed while this reel is run. The output volume is measured by the meter, and should be the same for all frequencies that the system is intended to reproduce. In some systems, however, the response at certain frequencies is intentionally made low or higher; this may be done to compensate for acoustic conditions of the theatre or for other reasons. We have seen that the amplifier of Fig. 201 included arrangements for varying the frequency response. In such cases the test reel and the output meter record the response when the desired modification has been obtained, and are employed thereafter to see that the response of the system has not changed.

The output meter or volume indicator used with the test reel for this purpose is really a disc-type-rectifier a. c. voltmeter, calibrated to read directly in decibels. As already stated, any voltmeter of the same type built to operate within the same range of power can be used instead by means of a simple chart, furnished with the instrument, to convert volts into decibels.

Another instrument that is always useful, and with some types of equipment indispensable, is a combination circuit-tester tube-tester of the kind used by radio repair men. These instruments are made in quantity production for radio dealers, and hence are not excessively costly. The later models are capable of checking the large tubes and high-voltage circuits used in sound equipment. A tester of this kind often contains only a single meter but a large number of switches. By operating the switches in accordance with instructions the same meter will read a wide range of d. c. volts, a wide range of d. c.

amperes, a wide range of d. c. milliamperes, several ranges of a. c. volts, a. c. amperes and a. c. milliamperes, and can moreover be used, with a conversion chart, to read decibels.

Simpler equipment that is also useful includes a test buzzer operated by a flashlight-type dry cell. This is very useful for testing through conduit wiring. It should not be used, however, without the precaution of disconnecting all apparatus that contains a sound transformer or a sound choke coil. Buzzer current must never be sent through those parts.

The small patented device called "Test-a-lite" is very handy in checking power circuits. It tells whether any circuit carrying more than 100 volts is "alive," and if so whether it is carrying a. c. or d. c.

In addition to instruments, the trouble-shooter needs detailed data, as previously explained. Checking circuits with a meter is thankless work unless the details of the wiring are known thoroughly or plainly visible on a drawing. Wiring diagrams accompany practically all sound equipment, either in the manufacturer's instruction book or pasted up inside each amplifier or other piece of apparatus. If they are found missing, ask or write for duplicates at once. Diagrams of the external transmission wiring between different parts of the system should also be available. These should, in every case, be compared with the actual existing wiring, using the test buzzer if necessary, to make sure that the drawing is an accurate representation of the circuits of that projection room, and if not, the drawing should be modified accordingly. If the theatre is receiving regular sound service the service engineer will be able to provide the proper drawing and modify it correctly if necessary.

With any of the more intricate sound systems, failure to have this information on tap may mean that a very simple trouble will tie up the show for hours, while the work of making complete and permanent repairs has been known, under such circumstances, to take several days, most of the time being used in tracing out unknown wires.

TEMPORARY REPAIRS

(7) A temporary repair is any expedient whatever that will restore the show in the shortest possible time. It need not be a remedy or rebuilding of any kind. It may be no more than switching out a faulty amplifier and running with the other amplifiers of the system. It may amount to a lamp cord run as a temporary transmission line outside of conduit until time can be found to trace down the break or short in the regular wires. Although cutting out an amplifier may result in low volume, and temporary transmission lines outside of conduit may cause noisy sound, either of these troubles may be preferable to tying up the show altogether until permanent repairs can be made.

Temporary repairs also include substitution of substandard or "haywire" parts while awaiting delivery of a proper replacement. The local radio store will be able to provide anything from a condenser to a complete amplifier. Storage batteries rented in emergency from the nearest garage will substitute temporarily not only for the theatre's storage batteries but also for its sound supply rectifiers or motor generator.

The possibilities of ingenious temporary repairs are almost limitless, but we shall say little about them here because such improvisations are always dangerous. (8) Temporary repairs are necessary and invaluable when they serve to restore the show faster than any other procedure could. They should always be avoided, however, (a) when permanent repair can be made with little more delay, and (b) when the projectionist is not entirely certain that damage to other apparatus is impossible.

Because they are dangerous except when applied by men who know exactly what they are doing, including the resistance or impedance of every part and circuit involved, temporary repairs should be planned carefully in advance. It is excellent practice to ask the sound service engineer, if there is one, or to inquire by mail of the manufacturer of the equipment, just what emergency steps may safely be taken in case of this, that or the other trouble.

PERMANENT REPAIRS

(9) A permanent repair involves not only restoration of the equipment to proper and permanent operating condition, but in addition every step of precaution that can reasonably be taken to avoid recurrence of the same trouble, or to avoid delay in the show if it does recur. This may quite possibly involve changing some portion of the equipment. In unusual and extreme cases it may mean buying a new sound system. Permanent repair may also involve taking advantage of the occasion to add some intended and valuable improvement, the installation of which has been delayed because of the cost of tearing the old system apart.

(10) In any case, a permanent repair is never completed until, first, the system is giving the best results possible to its design, and, second, until every reasonable precaution has been taken against further interference with the show.

Let us review the foregoing briefly:

The first step in finding trouble is to determine which portion of the system is responsible.

The second is trace down the faulty part or wire or contact within that apparatus or circuit.

(*The trouble charts of the next section go no further than this point. They will have done all the work they are intended for when they have guided the user to finding his trouble, or to making some replacement, change or adjustment that remedies it. Precautions to insure a permanent repair are beyond their scope, except for a few obvious warnings which are given in accompanying notes; nor do they cover more than a very few temporary procedures for restoring the show while trouble investigations continue.*)

Temporary repairs are very helpful in restoring the show quickly, but likely to endanger other apparatus unless they have been carefully planned in advance.

Permanent repairs are not complete until everything possible has been done to prevent re-appearance of the same trouble.

Let us now apply these necessary generalities to the problems of finding different classes of trouble. The treatment of individual troubles which follows may profitably be contrasted with the more detailed prescriptions of the trouble charts, and in particular should prove useful in modifying those charts to meet individual projection room conditions as recommended in the instructions that precede them.

Loss of Sound

(11) This is usually the easiest trouble to find. Headphones applied to the sound transmission lines should quickly locate the apparatus or circuit at fault. The difficulty is then checked through that apparatus as has previously been explained in connection with the description of each sound system component.

However, if the equipment is provided with meters and signal lamps even the brief time necessary for a headphone test can sometimes be avoided. A momentary glance at those indicators may locate the difficulty at once by revealing the component that has failed.

The remedy to be applied depends, of course, upon the cause, and involves repair of the broken circuit, elimination of the short, or replacement of the faulty tube or other part, as the case may be.

Low Volume

(12) This trouble is harder to trace than complete loss of sound. It may be possible to judge by a headphone test at what point the amplification is insufficient or the line loss excessive, but such investigation may also result in nothing more than doubts and surmises. It is, however, simple enough to determine whether the fault is associated with either projector. If it is, then all voltages to the faulty machine should be checked with a meter, if not, then those supply voltages that are common to both projectors, and after them to the amplifier should be investigated in the ways hereafter explained. In some cases, finding the cause of low volume may require a

long time and much patience. In very rare instances it may prove necessary to borrow duplicate parts in order to determine by comparison just where the trouble lies.

The volume indicator is a valuable instrument in this type of trouble. Knowing what the volume of the amplifier's output should be, with the test film previously used, the projectionist can tell by means of this instrument whether the cause of low volume is in the projection room or in the speaker circuits. If it is in the projection room and not confined to one projector either the amplifier or its transmission lines must be responsible. If there be both a voltage and a power amplifier the output meter (by comparison with previous results) may be able to determine which of the two is the faulty one.

Poor Quality of Sound

(13) This type of trouble will sometimes be found readily, perhaps with the help of headphones. Sometimes it proves more obstinate than any other.

The ways in which each separate portion of the sound equipment can cause poor quality have already been described in detail. In extreme cases it may be necessary to investigate them all, one at a time.

Fortunately, it is very often possible to determine the cause of poor quality by spending a little time in the auditorium and listening carefully. Once the difficulty has been classified, as, distortion, flutter, wows, loss of high frequencies, loss of low frequencies, et cetera, finding its cause is immensely simplified. The various conditions that can cause these different troubles have all been explained. Flutter and wows are due to imperfect functioning of the drive system. Loss of high frequencies may be caused by nothing more than bad focus of the exciting light, or yellow or insufficient exciting light. However, an open-circuited by-pass condenser in an amplifier can also be responsible. Or the power supply to the high frequency speakers may be faulty. Loss of low-frequency response may be due to a similar defect in connection with the low-frequency speakers.

Since "bad sound quality" is no one trouble, but may be any of a great number (some acoustical), there is no single remedy and no simple way of running it down. Patience, common sense and knowledge on the part of the trouble-shooter are indispensable for fixing bad sound. The output meter and the test film will prove of great help not only in determining whether the frequency response has deteriorated, and if so to what extent, but also in measuring precisely the result of any remedial measures that may be tried experimentally.

TROUBLE IN POWER SUPPLIES

(14) The voltmeter is the necessary instrument for running down a power supply line or power supply equipment. The first step should, in most cases, be to apply the meter to the switch or other output terminals of the power source. This shows at once whether the trouble is in the source or in the output line. Continued voltmeter tests must reveal the difficulty, unless, as explained further on, it be intermittent.

HUMS AND NOISES

(15) This type of trouble, again, does not represent a single condition, but involves any one of a vast number of possibilities.

The first step is to listen carefully to the hum or noise, attempting to classify its cause by what it sounds like.

The experienced projectionist will recognize at once the sound of sprocket-hole noise and dividing-line noise, both caused by mis-adjustment of the lateral guides. He will likewise find little difficulty in distinguishing between the low-pitched line-frequency hum and hums or whistles of higher pitch. Furthermore, he will be familiar with the rasping, rattling sound of a bad or dirty connection. These are the three commonest forms of foreign disturbance.

(16) Headphone tests may be helpful in dealing with them, by determining, for example, that the cause is in the voltage amplifier and not the power amplifier, or vice versa.

Line-frequency hums may be caused by amplifier conditions described in connection with the construction and functioning of amplifiers. They may also be caused by exposure of the photo-cell to the projection room light, if that is created by a. c. Another cause may lie with the ground connections, and this is a more tricky matter, in which trouble-shooting becomes largely experimental. The earlier sound systems often used a number of grounds, and sometimes line-frequency hums could be cured by adding still others, and sometimes by removing some of those already in use. The modern tendency is in the direction of a single ground connection for all the equipment. Corrosion or bad contact at this or any connection may easily create line-frequency hum in the sound.

Hums of other than line frequency are rare. They may, however, (as already explained) be caused by feedback in an amplifier. Or by loose connection in a grid circuit.

The crackling, buzzing or fizzing or rasping sound caused by most imperfect contacts can sometimes be run down by headphones, which may indicate what amplifier, supply line or other part of the system is the source of the trouble. Sometimes, however, much patience is needed before trouble of this kind is traced to its ultimate cause, which may be, perhaps, no more than a defective fuse.

INTERMITTENT TROUBLES

(17) Any of the above troubles becomes infinitely harder to find if it does not represent a permanent condition, but one that comes and goes. In such cases tests have no meaning unless they are applied at a moment when the trouble is present. The fact that an experimental remedy seems to work likewise means nothing with a trouble that constantly disappears of itself.

One very helpful procedure in these difficult cases is to attempt to make the trouble worse, rather than better. Wires are tugged, ground connections are rattled, rheostats and switches are operated rapidly and jerkily, tubes are tapped and panels tapped or shaken in an effort to cause or to aggravate the trouble and thus determine its location.

If these methods do not work the next best remedy is patient testing and searching at every possible moment when the trouble is present. Ultimately this adds up to continuous investigation of a trouble continuously present. In some cases, however, the process may take much too long for the comfort of audiences and the welfare of the box office. In such instances it is sometimes (not invariably) possible to make faster progress by borrowing duplicate apparatus for temporary substitution, or by running temporary duplicate circuits. Both these last steps, of course, represent remedies of desperation.

The foregoing does not exhaust the subject of trouble-shooting. A book much longer than this one could be written on that subject. Even the trouble charts that follow, although extremely detailed, are by no means exhaustive. While such things as complete loss of sound or power are nearly always easy to find, an intermittent hum or noise may defy the world's best trouble-shooter for days or even weeks. We have outlined here and in the charts methods that are likely to afford quick relief against all the commoner causes of sound trouble. For very rare troubles, or for common troubles arising out of a very rare cause, knowledge, common sense and persistence constitute the only possible rules.

REQUIREMENTS OF GOOD MAINTENANCE

(18) Good maintenance requires (a) that the equipment be kept in condition for reliable, trouble-free operation at all times, and (b) that it perform its functions at the lowest possible cost.

(19) Written, typewritten or printed forms for daily, weekly, monthly and semi-annual inspection are necessary to insure reliable operation. Without such forms the most experienced projectionist can never feel sure that he has remembered every necessary item of attention or adjustment.

(20) All the inspections just mentioned are not necessary in every theatre. Daily inspection is invariably

necessary. But the weekly inspection can sometimes be eliminated in favor of inspection every second week. Occasionally, if inspection is held every other week, the monthly inspection can be abandoned, certain additional items of care being included in the bi-weekly form. With equipment in good condition, new, but not too new, annual inspection may be used in place of one every six months.

The exact requirements vary according to the reliability of the sound equipment, its age, its condition, the nearness of the theatre to sources of engineering help and emergency supplies, the class of audience and corresponding importance of keeping the show running without interruption or defects, the alertness and experience of the projectionists, and several other factors.

But it is always necessary to inspect parts of the equipment daily, and other parts at reasonably short intervals, such as every week, every other week or every month. Lastly, some things that give little trouble and are difficult to get at must still be looked over once in a long while, every six months or every year.

These precautions not only protect the show, but also save money. Breakdown of one part very often will damage or endanger a dozen others. This is true in the drive system, it is true in amplifiers, and true in connection with power sources. Again, setting aside the undesirability of trouble from the point of view of audience dissatisfaction and possible box office refunds, the mere cost of making repairs may, and often will, be much greater than the cost of following inspection routines that catch and rectify the trouble before it grows large enough to need extensive repairs.

(21) The projectionist can draw up his own inspection forms. If printed forms are provided by the management he should modify them to take care of special conditions in his own projection room. It is not difficult to draw up an inspection list. In explaining amplifiers, speakers and other parts of a complete sound system we have listed the commoner troubles to which each is subject. The projectionist should study every separate part

of his sound installation, carefully considering what possible troubles must be guarded against in each, and how often it should be necessary to inspect for their symptoms. His inspection lists are prepared accordingly. Experience with the installation will naturally call for some modification or expansion of those lists from time to time.

If the theatre is receiving regular sound service only the daily list is necessary. The sound engineer will take care of everything else, insofar as the sound equipment is concerned, and the daily form should be submitted to him for his comment and advice.

(22) The daily form lists every item that needs care or attention daily, but just what these will be depends on individual conditions. (23) The weekly list mentions everything that needs to be done or watched weekly. The weekly inspection, if lengthy, need not be done all at once. It can be divided into parts, and some of it done each day. If there is no weekly inspection, but only one every other week, some items, which cannot safely be neglected that long, will have to be added to the daily form. (24) The monthly list includes attention to those parts that wear out rather slowly, and do not need very constant watching. Upon occasion, some part in poor condition may be transferred, pending replacement, to the weekly or even to the daily list. (25) The annual or semi-annual inspection is usually very thorough, including all those parts of the system that cannot be inspected often because they are difficult to get to, or because (as with the innumerable soldered connections) too much time is needed to do a thorough job of going over them. The annual check-up also includes those that are very slow to wear and consequently need attention only rarely.

Detailed knowledge of local conditions and good common sense are the necessary requirements for preparing such lists.

(26) The purpose of inspections, of course, is to insure that all necessary adjustments, repairs and replacements are made in advance of serious trouble. Inspec-

tion alone, not followed by adjustments, is meaningless. Minor matters, such as cleaning and lubrication, are attended to in the course of inspection. (27) Matters that cannot be cleared up promptly are noted on the form or list, which of course is never finally filed for record until every repair it indicates has been completed.

SOLDERING

(28) This factor in sound repairs is important enough to rate repeated attention, particularly since many projectionists fail to realize that what is good soldering in power work may be atrociously bad soldering in sound work. Soldering is used in power lines very largely to prevent the connection from opening, not particularly to secure low-resistance contact. The comparatively large voltage and current of a power line are not troubled by slight corrosion, or minor variations of resistance. But sound current may be as small as a micro-ampere (a millionth of an ampere) and sound voltages are very often of the order of one volt. Consequently slight variations in the resistance of a sound connection may create noisy sound, and a prolonged headache in the trouble-shooter who tries to run down the cause. Appreciable or even slight corrosion may result in complete loss of sound.

(29) Sound soldering is seldom done with an open flame. A copper is used, hot enough for the work. It is bad practice to melt the solder and let it drop on a cold wire. It is good practice, wherever possible, to heat the wire and let it melt the cold solder. Occasionally the contact stud of a condenser or transformer will refuse to heat readily. Prolonged application of the copper is dangerous in such cases. The stud may refuse to heat to the proper temperature until the internal wires or insulation have been seriously damaged. A hotter copper should be used. Open flame should be used only with great caution.

Sound connections are not made with acid but with rosin. Acid may cause corrosion.

A person experienced in sound soldering can safely create a physical connection by splicing two wires, or a wire to a terminal post, and then soldering the splice, but this practice is dangerous in hands that are not thoroughly skilled. The novice at sound soldering should tin both terminals and solder them together, providing no physical bond except the solder itself. After the joint has cooled, tug hard at one of the wires. If the joint was properly made it will not yield. But this valuable test is useless if there is a physical splice aside from the solder. That is why such splices should never be used by the novice. (Further details concerning soldering on Pages 62-65.)

TESTING SOUND PARTS

There are two reasons why sound parts are tested in the projection room. One is that such tests may be a necessary step in trouble-shooting. The other is equally important; no part should ever be stocked as a spare for use in emergency until tests have shown that it can be relied upon when needed.

TESTING RESISTORS

(30) Resistors are tested by use of an ammeter, a voltmeter, and application of Ohm's law. Such tests, however, check only the continuity and resistance of the part, not its current-carrying capacity. The latter factor cannot readily be checked in the projection room.

TESTING INDUCTANCES

(31) The inductance of coils is not usually measured in the projection room. They may be checked for short-circuit with a. c. and an a. c. milliammeter. Inductance coils* show a high impedance to a. c. which will be diminished or altogether absent if the coil is short-circuited internally. They are checked for open circuit with d. c. and a d. c. milliammeter, since direct current should pass through them with little loss unless the circuit is open.

TESTING TRANSFORMERS

(32) For projection room testing purposes the trans-

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*Never test any speech coil with more current than it is intended to carry in actual use.

former may be regarded as an instrument made up of two or more choke coils, each of which is tested separately. When there are many terminals the transformer casing, or the wiring diagram of the apparatus in which it was used, will show the internal connections.

Warning: Never test a speech transformer with more current than is necessary to operate a high-resistance voltmeter.

Testing Condensers

(33) Some combination circuit-testers-tube-testers contain provisions for measuring the capacitance of condensers, but this is not usually a matter for projection room test. Condensers are tested for internal short circuit with d. c. and d. c. ammeter or milliammeter, or a trouble lamp. Only short circuit of the plates will permit d. c. to pass through a condenser (except for a momentary charging current). Internal open-circuit is tested with a. c., which will not flow through the condenser if an open exists.

In testing electrolytic condensers with d. c. be careful not to reverse their polarity. In testing electrolytic condensers with a. c. be careful to apply the current for only a second or less.

Testing Tubes

(34) Many tube testers check amplification factor and mutual conductance (these are units in which the quality of tubes is measured). Normally, however, projection room tests do not go beyond reading plate current, which procedure is explained in our discussion of amplifier circuits.

Purchasing

The projectionist sometimes does his own buying of parts and spares, but in general practice this is attended to by the manager. The projectionist, in turn, tells the manager what he needs, and often advises on matters of quality and brand. Advising the manager intelligently in such matters is a proper and very important part of the maintenance duties of the projectionist.

STOCKING PARTS AND SUPPLIES

(35) Good practice with respect to stocking spares requires that the resources of the projection room shall be equal to all ordinary emergencies. There should always be enough tested tubes, exciter lamps, batteries and other parts on hand to avoid delay in replacing one that is faulty. The amount of money that must be invested in such insurance comes to very little in comparison with the possible cost of a prolonged interruption or defect in the show, caused by absence of some necessary and inexpensive article. The quantity of spares needed depends largely, of course, on the distance from the source of supply, and the rapidity with which emergency orders can be filled. Remotely located theatres should not only carry a full inventory of ordinary spares, but also replacements for any supposedly permanent parts (resistors. transformers, etc.) that may have shown themselves exceptionally subject to trouble.

SELECTING PARTS AND SUPPLIES

(36) Except where the theatre obtains all its sound parts from one source very careful life records should be kept of every part, and compared with the purchase price. Parts of different makes should be used under identical conditions, and their life records kept and compared. There is no other way for the theatre to be sure it is getting the best value for its money.

(37) A simple bookkeeping system is necessary if such records are to be kept properly and intelligently, and are to be available when wanted. But while the projectionist can easily make the necessary entries in the proper forms or books, and doing so is a logical part of his duty, he cannot fairly be expected to design a bookkeeping system. That is the function of the management. The projectionist should, however, ask that it be done, since life records not only reduce the cost of operating the projection room, but also insure that the projectionist is supplied with parts that last longer and give him less trouble.

Keeping of such records requires that each individual part be numbered so it can be identified after weeks or months of use. Gummed labels or china-marking crayon are used for this. In parts that generate or are subjected to intense heat such markings are not permanent, and should be renewed when necessary in the course of the weekly inspection.

(38) Experience with such records will be an invaluable guide to the projectionist when he is asked to advise on the selection of a new sound system, since the cost and trouble of maintenance is as important in that selection as quality of results or initial purchase price Some maintenance factors, for example, the rapidity with which certain parts will wear out, can only be guessed at, and guarantees should be asked to cover such points. Other maintenance factors are, however, subject to personal inspection of the equipment. The most important, perhaps, are simplicity of design and ease of accessibility, both being virtues that prevent unnecessary troubles and make those that are unavoidable easier to find.

TELEVISION AND RADIO COMPONENTS

Practical Questions

(For answer to each question see statement of corresponding number in Chapter XXVII)

1. Are electrical parts and components used in television and radio apparatus entirely different from those used in theatre sound equipment?
2. Do television and radio component parts differ completely in principle from those used in theatre sound equipment?
3. How do high frequency transformers and choke coils differ from low frequency types?

Variable Condensers, page 625

4. How are variable condensers used in television and radio equipment?
5. What effect has the spacing between a condenser's plates upon the capacitance of the condenser?
6. Describe a variable condenser.
7. What is meant by "ganging" variable condensers?
8. Where can any reader easily examine the operations of variable condensers?
9. What is a trimmer condenser and what is its purpose?
10. What would happen in a radio or television receiver if the trimmer condensers were out of adjustment?
11. How are trimmer condensers adjusted, or aligned?

The Cathode Ray Tube, page 628

12. Through what path may electrons emitted in a cathode ray tube return to their source?
13. May a cathode ray tube have more than one anode?
14. What corresponds to the grid of an amplifying tube and one common type of cathode ray tube?
15. Describe one of the anodes in a common type of cathode ray tube.

16. What electrical effects may be produced by charges upon the cylinder of a common type cathode ray tube?
17. What is the function of the deflecting plates or vanes in a cathode ray tube?
18. What is the function of the fluorescent material in a cathode ray tube and how does it cooperate in producing the television image?

The Television Camera, page 630

19. Describe in outline the construction of one type television camera.
20. Describe in outline the operation of one type television camera. Is its operation synchronized, in television work, with the operation of the cathode ray tube in the television receiver?
21. Are all television cameras basically alike?
22. Name some common variations in the construction of cathode ray tubes.

CHAPTER XXVII

TELEVISION AND RADIO COMPONENTS

(1) The electrical parts and components of television and radio apparatus are largely similar to those used in theatre sound equipment. Many are identical—that is, the same tube, resistor, condenser or other part may be equally suited to use in a sound amplifier or for television or radio purposes.

(2) Those television and radio components which are not of types used in theatres today are very often extremely similar in principle and construction. Even when there is some basic difference in principle, the electrical fundamentals will not be strange to the projectionist. There is, for example, ordinarily no such thing in the theatre as a cathode ray tube, but this tube works with electrons emitted into a vacuum and controlled on the same principles, if not in the same way, as the electrons in any tube.

(3) Transformers and choke coils used in television and radio work are often of high frequency types. Some are illustrated in Figure 37-B, Page 83. They differ from the low frequency transformers and choke coils with which all projectionists are familiar in that iron or alloy laminations cannot be used at high frequencies. The h.f. transformer and choke coil, therefore, is either wound on insulating material and called an air-core coil, or it is provided with a core of powdered iron or powdered alloy. Also high frequency windings, generally speaking, do not have as many turns of wire as low frequency windings. There may be no more than half a dozen turns of wire in the primary or secondary winding of an air-core radio or television transformer. At high frequencies, a few turns of wire may possess as much inductance as many turns at a lower frequency.

VARIABLE CONDENSERS

(4) It was noted in Chapter XVII that condensers and choke coils can be combined in circuit arrangements to constitute resonant filters which either will pass any desired frequency or band of frequencies, or will stop or short circuit any frequency or band of frequencies. Such filters are used in theatre sound systems, and they are occasionally adjusted by altering connections to their condensers, or to their choke coils or resistors. An example of a frequency filter used in sound equipment, and adjusted by changing condenser connections, is found in Figure 201. However, that filter, and others similar to it used in theatre work, are set once and left alone indefinitely. In radio and television work it is necessary to adjust frequency filters continually, and it is necessary that these filters be so made that they can be changed almost instantly to respond to an almost infinite number of different frequencies. Hence, condensers used for such purposes in radio and television work are built so that their capacitance can be varied at will and in infinitely small steps.

(5) The capacitance of any condenser depends in part upon the spacing between the plates. The closer together the plates can be brought the higher the capacitance. This, as noted on Page 88, is the reason why electrolytic condensers can incorporate very high capacitance in a small space—the insulation separating the plates is extremely thin. Figure 221 represents a variable condenser, commonly used in television and radio "tuning" circuits.

(6) All of the horizontal plates of Figure 221 are connected in parallel to each other, and, electrically speaking, constitute one plate. All of the plates shown in diagonal position in Figure 221 are connected in parallel and, electrically speaking, constitute the other plate of this condenser. By rotating the shaft to the right the diagonal plates of Figure 221 can be entirely disengaged from the horizontal plates, bringing the capacitance of the condenser to a minimum. By rotating the shaft in the opposite direction the plates shown in a

diagonal position in Figure 221 can be completely interleaved with the horizontal plates (they do not touch, of course) bringing the capacitance of the device to its maximum. Or, the shaft can be rotated to make the plates pictured diagonally in Figure 221 assume any intermediate position, thus providing any intermediate capacitance.

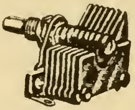
FIG. 221

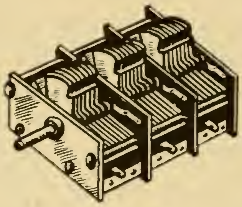
FIG. 222

FIG. 223

(7) It is often desirable, in radio and television apparatus, to alter the constants of several filter circuits simultaneously. To make this possible variable condensers are often "ganged." Three ganged variable condensers are shown in Figure 222. Their movable plates occupy a position which indicates that the capacitance of these condensers is, at the moment, approximately halfway between minimum and maximum. When the shaft of Figure 222 is rotated, the movable plates of all three condensers change position simultaneously. Each condenser is electrically insulated from the others.

(8) Any reader who wishes a still better understanding of variable condensers need only look inside any small radio, simultaneously tuning the radio. He will see an arrangement like that of Figure 222, and as he turns the tuning dial the movable plates will rotate to a different position. In short, tuning a radio is merely a matter of changing the capacitance of those frequency filter circuits which select a desired station frequency

out of the large number of frequencies induced in every receiving antenna.

(9) It would be impossibly expensive to attempt to build the device of Figure 222 with such extreme electrical accuracy as to assure that all three condensers will have exactly the same maximum, minimum and intermediate capacitances. In practice each of the three condensers of Figure 222 is equipped with a trimmer condenser. (A type of trimmer condenser is shown in Fig. 223.) A trimmer condenser is generally mounted on the side of each variable condenser of a gang. The trimmer consists merely of two small plates of metal, separated by mica or other insulation. The spacing of the plates can be changed by adjusting the set screw shown in Figure 223, thus slightly changing the capacitance of the trimmer. Since the trimmer is in parallel with its variable condenser, adjustment of these trimmers serves to line up the capacitances of the ganged condensers to a higher degree of accuracy than would be possible if the most elaborate efforts were used in manufacture.

(10) As stated, the reader can see these devices for himself by looking inside any small radio. He is less likely to find them visible in a large and expensive radio, because they most likely would be hidden under shielding which would have to be removed to make the tuning condensers visible. The reader is cautioned not to alter the adjustment of the trimmer condensers in the slightest degree. Readjusting them, a process called lining up, or aligning, requires the use of a radio frequency oscillator and an output meter, and some little experience or the supervision of a competent instructor. If the trimmers are out of adjustment the radio will emit squeals instead of pure sound, and a television image will be distorted or destroyed.

(11) In lining up trimmer condensers or otherwise aligning receiving equipment a measured signal input is obtained from a high frequency oscillator and applied to the receiver while the output is read on an output meter. The trimmers are adjusted to give maximum

output reading first at the highest acceptance frequency of the receiver then at the lower frequencies. If the receiver is of the super-heterodyne type the intermediate frequency trimmers may be adjusted first, and then the radio frequency trimmers. This work is not difficult, but it cannot be done successfully (except through pure luck) by anyone who does not have the proper equipment and some little experience or instruction.

The Cathode Ray Tube

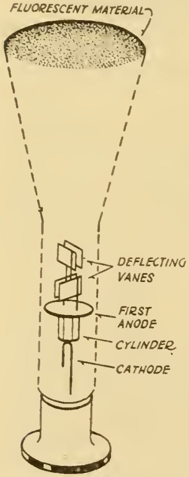

Fig. 224

(12) Figure 224 depicts a simple form of cathode ray tube with one intentional inaccuracy. The sloping sides of these tubes are coated with a black conducting material which constitutes the return path for electrons striking the white coating inside the wide end of the tube. That black material is omitted in the drawing in order that the internal parts of the tube may be clearly seen.

(13) Figure 224 is a vacuum tube equipped with a heater-type cathode, emitting electrons. It has two anodes, a "grid" of unusual shape, and it has deflecting plates which correspond somewhat to the negatively charged vanes of a beam power tube (Page 95).

(14) The cathode of Figure 224 is not clearly seen in the drawing. It is concealed by the lower end of the vertical cylinder, and emits its electrons principally into the lower opening of this vertical cylinder. The cylinder corresponds to the grid of an amplifying tube, being negatively charged. By virtue of its negative charge, it repels the emitted electrons so that they group together in a fine, hair-thin beam at the very center of the cylinder as they move toward the anode that is attracting them.

(15) The first anode is the horizontal disc seen in Figure 224 directly above the grid-cylinder. There is a hole in this disc directly above the center or axis of the cylinder. Most of the electrons of the beam do not

strike this first anode, but pass through that hole in its center and continue onward between the deflecting plates to the second anode—which is the white material at the wide end of the tube.

(16) The cylinder not only focuses the electrons into a fine beam, but also acts like any grid to control the strength of the current that reaches the anode. It may be so strongly biased, negatively, that it cuts off the space current entirely, driving the electrons back to the cathode. In that case it is said to be charged to cut-off. Or it may carry a somewhat weaker negative charge, permitting some emission to reach the second anode. A television signal impressed on this cylinder will vary the space current of the cathode ray tube between zero and maximum.

(17) The beam of electrons which emerges from the hole in the center of the first anode must pass between the two sets of deflecting plates before it can continue on to the second anode at the top of Figure 224. Alternating currents applied to these two sets of deflecting plates deflect the beam both vertically and horizontally and cause its needle-fine tip to scan left to right and up and down all across the surface of the white material at the top of Figure 224. As has been stated, the electrons striking that white material (which is semi-conductive) are returned to the negative side of the B circuit by a black coating which lines the sloping sides of the tube and is in contact with the white anode material but is omitted intentionally from Figure 224.

(18) The white material at the top of Figure 224 is fluorescent. Zinc sulphide, calcium tungstate and other substances have the property of emitting visible light when they are bombarded by electrons. As the tip of the beam strikes one point of the white fluorescent anode of Figure 224, that point emits visible light in proportion to the intensity of the electron bombardment. The action of the deflecting vanes causes the tip of the beam to scan back and forth, and up and down over the entire surface of this fluorescent material, in a small fraction of one second. If the beam is at maximum intensity

while it does this, persistence of vision will make an observer see the top of Figure 224 as a glowing surface. But if the action of the grid-cylinder is such as to change the intensity of the beam while the beam is scanning the anode, some parts of the anode will give off fluorescent light while others will emit less light or none at all and an observer will se a pattern of blacks, whites and grays. This is how the television picture is formed in cathode ray television receivers.

THE TELEVISION CAMERA

(19) The television camera is no more the concern of the projectionist than is the microphone of a recording studio. Nonetheless some idea of how the television signal is created is necessary to a complete understanding of how that signal is reproduced as a visible image. Therefore we shall deal very briefly with one type of television camera. It is not too greatly different in construction and principle from the cathode ray tube of Figure 224, but it operates in the reverse way. It has a cathode, a grid-cylinder, which concentrates the emission into a fine beam of electrons and it has either deflecting vanes within the tubes or deflecting magnets outside the tube, by means of which the electron beam is made to scan the entire surface of an anode, just as in Figure 224. The anode is not coated on the inside of the glass but on a metal plate. The beam of electrons strikes this metal plate and scans it at an angle. (The resulting keystone is compensated for in the scanning circuits which deflect the electron beam.)

(20) The image to be televised is focused upon the anode of the television camera. This anode is coated with photo-electric material finely dispersed throughout an insulating medium, somewhat as the silver particles that make up an ordinary photographic image are finely dispersed throughout the emulsion. This dispersion of photo-electric material in an insulating medium is called the mosaic of the television camera. When an image is focused upon the mosaic of the camera, each photoelectric particle of the mosaic emits one or more electrons, ac-

cording to the intensity of the light falling upon it. Thus each illuminated particle acquires a positive charge by virtue of having emitted negative electrons. The mosaic, however, is scanned, left to right and up and down, by the needle-fine point of the electron beam and the charged photo-electric particles lose their positive charge by acquiring electrons from the electron beam. The corresponding fluctuation in beam strength amounts to a variation in the space current of the camera tube, which variation constitutes the television signal. This signal, amplified and transmitted to the receiving apparatus, is used to vary the negative charge on the grid-cylinder of Figure 224. If the scanning beam in the television camera and the scanning beam in Figure 224 can be made to move in exact synchronization with each other (exact to the three-millionth of a second) then, whenever the scanning beam of the television camera touches a brightly illuminated part of the mosaic, the corresponding spot on the fluorescent material of Figure 224 will glow brightly. Whenever the scanning beam touches a completely dark portion of the image focused on the camera mosaic, the scanning beam in Figure 224 will be cut off by the action of the grid-cylinder, and the same section of the fluorescent material of Figure 224 will emit no light. An important part of television transmission circuits relates to the arrangements that cause the scanning beam in the camera and the scanning beam in Figure 224 to move in precise synchronization.

(21) All television cameras do not correspond exactly to the description just given. There are various models, incorporating differences that are usually covered by patent, but the basic idea of converting a visible image into an alternating current is the same in all, and while the methods used are not always the same, they are at bottom largely similar.

(22) All cathode ray tubes are not identical in construction with that of Figure 224. Some are more complex. Some have two anode discs and two grid-cylinders instead of one of each, as in this illustration, and there are other variations of detail. But all operate upon what is basically the same set of principles.

TELEVISION AND RADIO TRANSMISSION

Practical Questions

(For answer to each question see statement of corresponding number in Chapter XXVIII)

1. Are radio signal currents and television signal currents alike? Which is the simpler?
2. What general type of amplifier is used to strengthen the output current of a broadcasting microphone?
3. Can that amplified current be broadcast? Explain.
4. What familiar device is used to generate the alternating current frequency which a radio station is authorized to broadcast?
5. Can an ordinary amplifying tube be made to convert d.c. to a.c.? How?
6. How does a radio frequency amplifier differ from other amplifiers?

MODULATION, PAGE 635

7. What is a carrier current? What is modulation? Describe the type of current created by ordinary modulation of a carrier current.
8. Describe briefly the type of current created by frequency modulation.
9. Explain why television broadcasting is limited to distances within the horizon.

TELEVISION TRANSMISSION, PAGE 636

10. Name one difference between radio transmission of sound and radio transmission of television.
11. When sound is broadcast what band of frequencies is impressed upon the carrier current by modulation?
12. Must a wider band of frequencies be impressed upon the carrier current in order to broadcast television?
13. What is the maximum frequency impressed upon the carrier current in television broadcasting?
14. What is the "video" frequency? What currents in addition to the video frequency are impressed upon the television carrier?

CHAPTER XXVIII

TELEVISION AND RADIO TRANSMISSION

(1) The radio signal is simpler in nature than the television signal and therefore it will be helpful to outline first the transmission of sound radio and, thereafter, the transmission of television by radio.

(2) In any broadcasting station the sound current created by a microphone or phonograph pickup is amplified in the ordinary way to a volume corresponding with the power which the station is permitted to broadcast. If that power is 5 kilowatts or more, the output stages of the sound amplifier are commonly equipped with water-cooled tubes. However, there is nothing about the sound amplifier in the radio broadcasting station that differs essentially from sound amplifiers in theatres.

(3). The amplified sound current cannot be broadcast. If it were placed on the transmitting antenna, no receiver except one very close by could pick it up. The highest sound frequencies, those near 5000 cycles, might radiate to a very slight degree. The lower frequencies would not radiate at all, except by ordinary induction and therefore extremely short distances. Alternating currents of more than 50,000 cycles are needed to obtain useful radiation. The sound to be broadcast must be transmitted on a "carrier" of radio frequency.

(4) Therefore, in every broadcasting station there is a device for generating radio frequency current. This generator is nothing but a small vacuum tube. Any three-element tube can be made to act as a generator of alternating current by introducing feedback between plate and grid. In Figure 201, a theatre amplifier, such feedback is introduced, but in reverse phase and is called inverse feedback. It operates to reduce volume and purify sound quality. But a polarity reversing switch

or any other means that would reverse the phase of the feedback in Figure 201 would cause the amplifier there depicted to generate alternating current. The frequency generated would depend on the inductance and capacitance of the associated circuits.

(5) If an ordinary old-fashioned telephone receiver is held close to the telephone mouthpiece the telephone will emit a loud squeal. In public address work if the microphone is brought too close to the loud speaker the whole system will emit nothing but a loud squeal. If the phase of the feedback of Figure 201 were reversed the sound system incorporating that amplifier would emit only an intense howl. The principle is the same in every case. If the output is brought back to the input and if the loss in such feedback is less than the gain in the amplifier, oscillation, or the generation of alternating current, results. In any three-element tube if the plate circuit is coupled, inductively or otherwise, to the grid circuit, and if the loss in such coupling is less than the gain or amplification of the tube, the tube becomes the generator of alternating current. It is then spoken of as an oscillator tube. The frequency of the current thus generated depends, as said, on the inductance and capacitance of the circuit. In broadcasting stations one of the condensers in the oscillating circuit is built with a carefully ground quartz plate as its insulating medium. Like the Rochelle Salt crystals referred to in Chapter XX, such a quartz crystal vibrates when alternating current is impressed upon the plates of the condenser of which it is a part, but the quartz crystal can vibrate at only one frequency—that for which it is ground. Hence this crystal-condenser permits the oscillator tube in the broadcast station to generate only one frequency. The crystal-condenser will, however, vibrate at a different frequency if its temperature changes; it is therefore kept in a small, electrically heated compartment where temperature is accurately controlled by a thermostat.

(6) The output of the oscillator tube, which is a.c. of the frequency the station is authorized to broadcast,

is amplified by a radio frequency amplifier up to the same power as the sound frequencies—that is, the maximum power the station is licensed to use. A radio frequency amplifier is simply an ordinary amplifier in which transformers, if used, are of radio frequency, air-core types, and consist of only a few turns of wire.

Modulation

(7) The radio frequency current—which will radiate if impressed upon a transmitting antenna—is the so-called carrier current. The sound frequencies are impressed upon the carrier frequency by a process called modulation. In amplitude modulation the effect is to vary the volume of the radio frequency in accordance with the volume and frequency of the sound current.

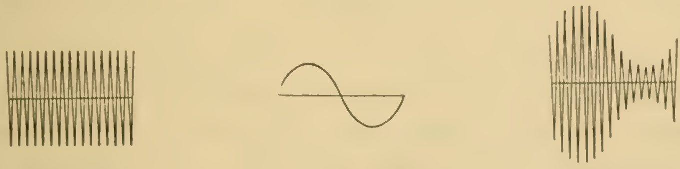
UNMODULATED R-F CARRIER
A-F MODULATING WAVE
MODULATED R-F WAVE

Figure 225

This is illustrated in Figure 225. The commonest method of effecting modulation is to connect the secondary of the output transformer of the sound amplifier with the primary of the output transformer of the radio amplifier. Thus the sound current flows in the output circuit of the radio amplifier, modifying the plate voltage of the output stage of the radio amplifier in accordance with the frequency and volume of the sound current. The secondary winding of the radio frequency output transformer is connected to the broadcasting antenna. The current in that antenna is illustrated at the right-hand side of Figure 225, its radio frequency varying in volume at the frequencies of the sound current, the extent of this variation in r.f. volume depending upon the volume of the sound current.

(8) Another type of modulation is known as fre-

quency modulation. With such modulation the antenna current is all of the same volume (as shown at the left of Figure 225) while the sound current superimposed upon the carrier is represented by changes in the radio frequency.

(9) Radio frequencies of less than 100 kilocycles require great power to make them radiate over long distances. Radio frequencies from 100 kilocycles up to several thousand kilocycles require progressively less power to radiate to great distances. All these frequencies are reflected by the ionized layer of the upper air, called the ionosphere or Heaviside layer, and are thus enabled to follow the curvature of the earth. Beginning about 3,000 kilocycles, roughly speaking, radio frequencies are not evenly reflected by the ionosphere, and tend to be received only at "skip distances." Still higher frequencies, such as those used for television transmission, often are not reflected at all by the ionosphere but penetrate through it and continue on into outer space. Such frequencies cannot be transmitted beyond the horizon, since the fact that the ionosphere does not reflect them makes it impossible for them to follow the curvature of the earth. This is the reason why radio transmission of television signals, which utilizes carrier frequencies of 10,000 kilocycles or more, is limited to distances within the horizon. By placing the transmitting antenna on a tall hill, or at the top of a tall building, the horizon can of course be widened, to a radius of possibly fifty miles in practice. "Freak" transmissions of several hundred miles have taken place with these "ultra" frequencies but are not common and cannot be relied upon for any commercial purpose.

TELEVISION TRANSMISSION

(10) Television transmission is commonly transmitted by means of radio frequency carriers, essentially in the same way as sound broadcasting. However, the television signal is different in nature from the sound signal, requiring a higher carrier frequency.

(11) The sound signal, in radio broadcasting, is gen-

erally limited to 5,000 cycles top, although a few stations have special license to broadcast up to 8,000 cycles of sound current. The lower limit of sound frequencies is, as in the theatre, very approximately 50 cycles. These frequencies are impressed by modulation, as said, upon the r.f. carrier frequency.

(12) The television signal consists of several parts, since synchronizing impulses to keep the camera and cathode ray tube in step must be broadcast along with the signal proper. The signal alone occupies a vastly wider spectrum of frequencies than does sound current.

(13) If the television standard is 441 "lines"—meaning that the point of the electron beam scans the fluorescent material 441 times from top to bottom, and if the equipment can respond to 588 "points" along each "line," then the total frequency involved in scanning the fluorescent surface once must be 588 x 441, or approximately 260,000 pulsations. But this frequency would give only a still picture. Television utilizes 30 "frames" per second (instead of 24 frames per second as in the case of motion pictures). The total number of pulsations per second to permit 30 frame transmissions would then be 260,000 x 30 or very approximately 7,800,000. Counting each pulsation as one alternation, and two alternations to one cycle, the transmission frequency necessary in the case of 260,000 picture elements at 30 frames per second would be 7,800,000 ÷ 2, or 3,900,000 cycles. In practice this maximum frequency is never realized nor needed because no image consists of contrasts at every point. There will be some areas which are all black or all white or all the same shade of gray and when the electron beam scans such areas there is no fluctuation in its strength. In practice a frequency of 3,000,000 cycles is adequate. It is called the video frequency.

(14) In addition to this video frequency, however, synchronizing impulses must be transmitted. These impulses control the action of the deflecting vanes of Figure 224 and hence keep the electron beam in Figure 224 in exact step with the electron beam in the television camera. They also increase the bias of the grid-cylinder

of Figure 224 to cut-off. (Thus the scanning beam is broken while it "flies back.") When the beam is restored the charges on the deflecting vanes are such that the beam-tip begins a new cycle of scanning the fluorescent surface.

The foregoing is, of course, only an outline of the requirements of radio and television transmission. Some details of the receiving apparatus used to meet these requirements now will be described.

TELEVISION AND RADIO RECEIVERS

Practical Questions

(For answer to each question see statement of corresponding number in Chapter XXIX)

1. Which apparatus is the simpler, a radio receiver or a television receiver?
2. If the radio receiving antenna is regarded as the secondary of a "transformer," how many primaries has that "transformer"?
3. Describe and diagram a circuit in which frequency filters and an amplifier are combined for selective amplification.
4. What is demodulation? What is a detector?

THE SUPERHETERODYNE RECEIVER, PAGE 642

5. Draw a block schematic of a superheterodyne receiver.
6. What is a beat frequency?
7. What is a pentagrid converter? What is its purpose?
8. What special feature is often incorporated in the transformers of an intermediate frequency amplifier and what is its advantage?
9. Is there any essential difference between the second detector of a superheterodyne receiver and the demodulator of simpler receivers?
10. Where can any reader readily find further details concerning the circuits outlined thus far in this Chapter?

THE TELEVISION RECEIVER, PAGE 644

11. Name four differences between a television receiver and an ordinary superheterodyne receiver.
12. What band of frequencies is a video amplifier designed to handle?
13. To what device is the output of a television video amplifier connected and what function does the output signal perform in that device?

SCANNING IMPULSES, PAGE 645

14. What components generate the alternating currents applied to the deflecting vanes of a television cathode ray tube?
15. What is meant by interlaced scanning?
16. What is a saw tooth frequency and how can it be generated?
17. How is the scanning action of the cathode ray tube electron beam synchronized with the scanning action of the television camera's electron beam?
18. How many saw tooth oscillators are needed in a television receiver?
19. How are horizontal and vertical scanning impulses separated in the television receiver?
20. What precaution makes certain that the video signal will never interfere with the synchronizing action of the scanning impulses?
21. What happens to the electron beam in the cathode ray tube during the period of "fly back"? Why?
22. Is there only one method of generating saw tooth impulses? Is there only one method of deflecting the cathode ray tube electron beam? Is there only one method of arranging the oscillator circuit of a superheterodyne receiver?

CHAPTER XXIX

RADIO RECEIVERS

(1) Radio receiving and reproducing apparatus is simpler than that used for television, although both operate on the same basic principles. According to the plan hitherto followed in these pages the fundamentals of common-type radio receivers will first be outlined, and will be followed by a description of how similar receivers are used for the more complex purpose of handling television signals.

(2) All radio broadcasting is picked up by some form of antenna, which may be regarded without too much inaccuracy as the secondary of a transformer of which the transmitting antenna is the primary. The antenna may be built into the radio, or if the radio is not perfectly shielded some of its r.f. transformer windings may act as an antenna. Every antenna is, of course, constantly exposed to an immense number of signals—may be regarded as the secondary of a transformer in which every transmitting antenna in the world is a primary. To select the signal desired from the multitude that are picked up by the antenna, frequency-selective filter circuits are used.

(3) In the simplest form of radio receiver the frequency filter circuits and the radio frequency amplifier are combined. The principle is diagrammed roughly in Figure 226, which represents an ordinary transformer coupled amplifier built around radio frequency air-core transformers. But the secondary coil of each transformer is bridged by a variable condenser and therefore that secondary and the condenser constitute a filter circuit which is also a part of the radio frequency amplifier circuit. The two condensers shown in Figure 226 are ganged as explained in Chapter XXVII, and both are

tuned by adjustment of the same control. This amplifier filter circuit will reject all the multitude of signals received by the antenna except those of the radio frequency to which the circuit has been tuned.

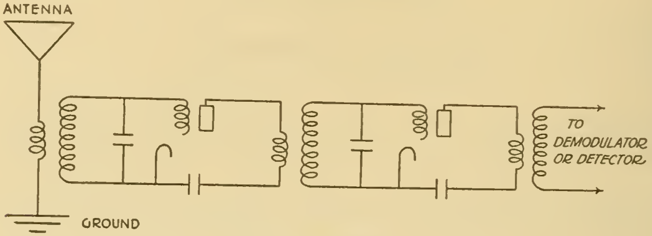

FIGURE 226

DEMODULATION

(4) The output of Figure 226 is a modulated radio frequency current of the type shown in the right of Figure 225. This current must be separated into its radio frequency and audio frequency components. That is done in what is called a demodulator or detector circuit, which includes a tube or a part of a tube. The detector is essentially a rectifier converting the output of Figure 226 into pulsating direct current. That current is then applied to a circuit that can accept the audio frequency component but cannot accept the radio frequency component. The final output of the detector or demodulator circuit is therefore simply audio frequency—the same audio frequency that was used to modulate the radio frequency in the broadcasting station. This audio frequency output of the detector or demodulator stage of the radio receiver is then wired to a common sound amplifier from which it is passed to a loud speaker. The modulator's rectifying elements and the first elements of the sound amplifier often are combined in one tube.

THE SUPERHETERODYNE RECEIVER

(5) The superheterodyne receiver is shown in block schematic in Figure 227. The output of the antenna is applied to an r.f. amplifier as in the case in Figure 226.

In a small, inexpensive superheterodyne receiver the r.f amplifier may be omitted and the antenna signal may be applied directly to the first detector.

(6) The phenomenon known as heterodyning produces a "beat" frequency or component when two different frequencies are present simultaneously. If the two frequencies are, say, 1,000,000 cycles and 500,000 cycles, their presence in the same wire will produce a "sum" frequency of 1,500,000 cycles and also a "difference" frequency of 500,000 cycles. The oscillator in Figure 227 incorporates in its circuit a variable condenser which is ganged with the other variable condenser of the superheterodyne receiver in such a way that the oscillator always generates a frequency which will heterodyne that frequency being received at the moment to produce a "beat frequency" of a predetermined number of cycles. If, for example, the i.f. amplifier portion of Figure 227 is designed to work at 500,000 cycles, the oscillator will generate a 300,000 cycle current when the tuning control is set to receive an 800,000 signal, thus producing a 500,000 cycle intermediate frequency. But if the tuning control is shifted to receive a 1200 kilocycle signal the corresponding change in the setting of the tuning condenser of the oscillator will make the oscillator deliver a 700,000 cycle output, again producing a 500 kilocycle intermediate frequency.

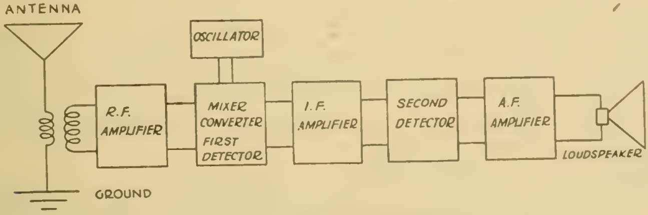

FIGURE 227

(7) Sometimes the oscillator and the mixer of the first detector are two separate tubes but very often they are a single tube known as a pentagrid converter, a tube with one cathode and one plate, and five grids interposed in succession between cathode and plate. Some of these

grids act as the oscillating portion of the tube, others receive the signal from the r.f. amplifier. The output of the tube is the beat frequency which goes to the intermediate frequency amplifier.

(8) The intermediate frequency amplifier is quite similar to the one diagrammed in Figure 226 but the transformers are sometimes of the powdered iron core type and in themselves are very sharply tuned to accept only that intermediate frequency for which they were designed. Since the i.f. amplifier operates on one frequency only—the beat frequency—it has no variable condensers.

(9) The output of the i.f. amplifier goes to the second detector, which is the same as the demodulator or detector of Figure 226, and the output of the second detector of Figure 227 goes to an ordinary sound amplifier and thence to a loud speaker.

(10) The details of these common radio circuits of course cannot be given here; this entire Blue Book could be filled with the details of radio circuits, and it still would not be large enough to hold them all. Such data are readily available in many books that deal with radio. The underlying principles are all that can be given here without sanctifying space needed for projection details that cannot be found in any other book.

The Television Receiver

(11) The television signal proper, ranging from 0 to 3,000,000 cycles per second, and impressed upon a carrier frequency which may be as high as 60,000 kilocycles, is received and reproduced by superheterodyne equipment in essentially the same way just described. The radio frequency amplifier section in the television receiver of course is built with r.f. transformers and variable condensers suited to accepting frequencies as high as 60,000 kilocycles; the intermediate frequency section is tuned to possibly 7,000 kilocycles (instead of possibly somewhere around 500 kilocycles as in the case of a common broadcasting receiver), and the output of the second detector goes to a video amplifier capable of dealing with a

signal current of 0 to 3,000,000 cycles. The output of the video amplifier then goes to the cathode ray tube of Figure 224.

(12) Up to the second detector there is nothing about the television superheterodyne receiving system that is importantly different from any sound superheterodyne radio receiver. The television receiver works with a higher band of frequencies, but it works on the same basic principles. The video amplifier, in turn, is not particularly different from a sound amplifier; the sound amplifier is designed to deal with frequencies from 50 to 5,000 or 8,000 cycles, whereas the video amplifier is designed to handle frequencies from 0 to 3,000,000 cycles, but this difference is a matter of the design of such component parts as transformers and choke coils, not a matter of important difference in circuits. The television circuits proper begin at the output of the television amplifier and are interposed between the output of that amplifier and the controls of the cathode ray tube.

(13) The signal output proper—that is, the 0 to 3,000,000 cycle current corresponding to differences in light and shade in the transmitted image—involves no complexities. This output is wired, as has been said, to the grid-cylinder of the cathode ray tube. It is essentially a voltage output rather than current output and is used to alter the voltage of the grid-cylinder, thereby modifying the intensity of the electron beam from moment to moment. The synchronizing impulses which accompany the signal proper involve some circuits new to the projectionist, which will now be described.

SCANNING IMPULSES

(14) The alternating currents applied to the deflecting vanes of Figure 224 are generated in the receiver, by oscillator tubes incorporated for that purpose. The action of those tubes, however, is controlled by synchronizing impulses received from the transmitter, for the purpose of assuring that the electron beam in the cathode ray tube will be in perfect step with the electron beam of the television camera.

(15) In order to reduce flicker, scanning is interlaced, the tip of the scanning beam following a path of the type shown in Figure 228. The entire field is scanned twice for each frame. Though there are 30 frames per second the field is scanned 60 times a second. The first scanning may take "lines" 1, 3, 5, 7, 9, etc., all in 1/60th second, and the second scanning take in "lines" 2, 4, 6, 8, 10, etc. Each such scanning constitutes one-half of a complete frame, the entire frame being scanned in 1/30th second.

(16) In order to make the electron beam follow a path of the type shown in Figure 228, "saw tooth" frequencies must be applied to the deflecting vanes of Figure 224. If the deflecting frequencies were "pure" or sinusoidal a.c. of the type diagrammed in Figure 8, Page 36, the beam would follow a sinusoidal path. To make it follow a saw tooth path like that of Figure 228, "saw tooth" frequencies must be used. This type of frequency is characterized by a slow increase in voltage followed by a sudden, trigger-like reversal of voltage, which causes the electron beam to "fly back" almost instantly. There are several circuits that can be used with an oscillating tube to make it generate a saw tooth a.c. One popular device for this purpose is a gas-filled triode with a condenser connected across from plate to cathode. While this condenser is in process of charging the voltage across it builds up for a time very regularly. When the voltage reaches a critical point the gas ionizes and in consequence there is a sudden rush of current through the tube between cathode and plate. This surge of current reduces the plate voltage below the point necessary to maintain ionization of the gas. Then the gas returns to normal (deionizes), the excessive space current is reduced, and the plate voltage rises again until after a fraction of a second the gas again ionizes and another surge of current passes through the tube. The charge upon the condenser connected between plate and cathode undergoes a saw tooth fluctuation accordingly. The frequency of the saw tooth a.c. is governed by the grid bias applied to the tube, by the capacitance of the plate-

cathode condenser, and by the ohmage of the plate resistor. The saw tooth character of the output is diagrammed in Figure 229.

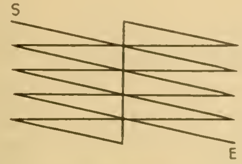

Figure 228

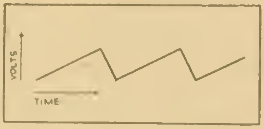

Figure 229

(17) The frequency normally developed by the saw tooth oscillator is made lower than that required for synchronous operation. When a synchronizing impulse from the transmitting station is received and applied to the grid of the saw tooth oscillator tube the change in grid voltage causes the gas to ionize sooner, in each alternation, than it would otherwise—that is: at lower plate voltage. In consequence the synchronizing impulse increases the frequency of the output of the saw tooth generator to that required for synchronization with the television camera.

(18) There are two saw tooth oscillators, one for the horizontal deflecting vanes and one for the vertical deflecting vanes, each operating at its own frequency.

(19) Synchronizing impulses for the horizontal-scanning saw tooth oscillator are transmitted each time the electron beam in the television camera reaches the end of one line. Impulses governing the saw tooth oscillator for the vertical vanes are transmitted each time the electron beam reaches the bottom of the television camera mosaic. These impulses are, therefore, of different frequencies, and are separated in the television receiver by frequency-selective filters. Each then is applied to the saw tooth oscillator for which it is intended.

(20) The synchronizing impulses are transmitted at higher volume than the 0 to 3,000,000 cycle video impulses. Therefore, even if, through some accident in the pattern of the picture to be transmitted, the picture current should momentarily have the same frequency as one

of the synchronizing impulses, no change in scanning would follow. At any frequency the signal impulses are purposely made too weak to actuate the grids of these scanning circuits.

(21) Additionally, the scanning impulses, when received, are applied not only to their own saw tooth oscillator tubes, but they are also connected with the grid-cylinder of the cathode ray tube. In virtue of the fact that they are considerably stronger than the video frequencies they cut off the electron beam in the cathode ray tube entirely during the period of "fly back." In other words, when the beam has reached the end of one line it "goes out" and resumes again at the beginning of the next line. Similarly when it has reached the bottom of the field it is cut off and resumes at the top of the field.

(22) The reader will understand that only one method of achieving given results has been described here and even then only in outline. The gas-filled triode is not the only tube arrangement that can be used to generate saw tooth impulses; other tubes in other circuits are sometimes employed. There are cathode ray tubes in which deflection of the electron beam is secured by means of magnets mounted outside the tube instead of by means of vanes inside the tube. The basic outline of the superheterodyne receiver does not vary, but, as said, the oscillator circuit of that receiver may embody a separate tube or may be incorporated with the first detector circuit in a pentagrid converter arrangement. It is not possible to go into the vast number of details which permit the general methods outlined to be applied through patented differences in component parts and specific circuits. The space available allows only a general outline of the basic principles underlying the performance of theatre television equipment, and one example, at most, of how each of those principles is embodied in concrete apparatus.

SOME TELEVISION DETAILS

Practical Questions

(For answer to each question see statement of corresponding number in Chapter XXX)

1. Name two ways in which a cathode ray tube television image can be projected to a theatre screen.
2. Do all television receivers incorporate cathode ray tubes for forming the image?
3. Describe in outline how light from a projection arc lamp can be made to vary in intensity for the purpose of forming a television image.
4. Explain in outline how light obtained from a projection arc lamp can be made to scan the surface of a theatre screen in forming a television image.

METHODS OF TRANSMISSION, PAGE 652

5. What apparatus is needed in the theatre for simultaneous reception of sound and television via radio?
6. What apparatus is needed in the theatre for simultaneous reception of sound and television via telephone line?
7. How far can a television signal be carried by telephone line? Will coaxial cable carry a signal over greater distances?

TELEVISION FILM PROJECTORS, PAGE 653

8. Is television sometimes used to transmit motion pictures rather than actual scenes?
9. Under what circumstances can a common photo-electric cell take the place of a television camera? Explain.
10. What device sometimes takes the place of the intermittent movement in projectors used for television?
11. Describe a modification of the intermittent movement incorporated in some projectors used for television purposes.

CHAPTER XXX

SOME TELEVISION DETAILS

(1) In cathode ray type television receivers there is no basic difference between the home receiver and the theatre receiver. In theatre equipment, however, the cathode ray tube is larger and in some models uses anode potentials as high as 50,000 volts. These potentials, incidentally, are dangerous to life and their circuits must be handled with utmost caution. The image formed at the base of the cathode ray tube may be projected to the theatre screen by means of either a simple lens or a parabolic mirror. When a mirror is used the cathode ray tube faces it at an angle so it will not intervene between the mirror and the projection screen. The keystone effect resulting from this angular placement of the CR-tube is counteracted by suitable adjustment of the circuits actuating the deflector vanes.

(2) There is a type of television receiver which does not use a cathode ray tube for forming the image. The source of light, in that system, is a projection arc lamp. Scanning is effected mechanically by means of two systems of mirrors. The light of the arc lamp is not focused upon the whole screen, it is concentrated into a flat beam and scans the theatre screen in much the same way as the electron beam scans the fluorescent surface of the cathode ray tube, and at the same rate of speed. This scanning action is synchronized with the scanning action of the electron beam in the television camera.

(3) The beam of light from the arc lamp must be made to vary in intensity from moment to moment, in accordance with the 0 to 3,000,000 cycle picture or video frequency. For this purpose it is passed through a glass-sided light valve. This valve is filled with a transparent liquid having an index of refraction suited to the other

constants of the optical system. Butyl bromide is the liquid used in the United States. Heptane has also been used. When there is no signal the light beam emerging from the valve is focused upon an opaque barrier which blocks it entirely and keeps it from reaching the theatre screen.

Built into the light valve is a small crystal which, like a crystal loud speaker, vibrates in accordance with the received signal. It imparts that vibration to the butyl bromide. A train of waves of compression sweep across the liquid at the frequency and intensity with which the crystal oscillates. Where the liquid is compressed by these waves its index of refraction is altered, the light beam is deflected accordingly, does not come to focus on the opaque barrier, consequently is not obstructed by that barrier and eventually reaches the theatre screen as a concentrated beam of light. The intensity of the light depends upon the degree of compression of the butyl bromide and therefore upon the volume of the received signal. The frequency with which the light is enabled to reach the theatre screen depends upon the frequency of the received signal.

(4) To cause the light beam to scan the screen there are two "mirror polygons," or wheels with mirrors set around their edges. One revolves horizontally and the other vertically. The former revolves more rapidly than the latter. It carries the light beam across one "line" of the theatre screen. Fly-back across occurs when the edge of one mirror passes beyond the beam limit and the edge of the next mirror comes into the beam.

The horizontal mirror polygon, however, does not reflect the light beam to the theatre screen directly. It reflects it to one of the mirrors of the low speed mirror polygon which causes vertical scanning. From that mirror the beam is reflected to the theatre screen.

The motor of the low speed or vertical-scanning polygon is driven by the synchronizing impulses received from the transmitting station, those impulses having first been amplified to the point where they are strong enough to drive the motor. The motor of the high speed or horizontal-scanning mirror polygon has two windings, one being asynchronous and excited by a 500 cycle current generated by an oscillator tube and amplified. The other winding of this motor, which controls synchronous operation, is powered by the horizontal-scanning impulses as received from the transmitting station and amplified.

Methods of Transmission

(5) When television signals are received in the theatre by radio two different receivers tuned to two different frequencies are used. One is the television receiver, the other is a sound radio receiver which picks up the accompanying sound. Sound and television are not broadcast on the same frequency nor necessarily on related frequencies. However, they are broadcast in synchronism and therefore are received and reproduced in synchronism.

(6) Radio is not always employed for television transmission. Over very short distances, a half-mile or so, ordinary telephone lines may be used to carry the 0 to 3,000,000 cycle television signal and its accompanying synchronizing impulses. A second telephone line may be used to supply the sound. When the signal is transmitted by wire the superheterodyne receiver, of course, is not needed. The signal is the same as that which is delivered by the second detector of the superheterodyne radio receiver. All that is needed is the video amplifier and the synchronizing saw tooth frequency generators. On the sound end also no radio receiver is needed—only a sound amplifier and loud speakers.

(7) For wire transmission over distances of more than a half-mile or so a telephone line is impractical. Coaxial cable must be used. This is the same type cable used in many theatres to couple the photo-electric cell to its amplifier—one conductor inside insulation surrounded by the other conductor, the outer conductor being grounded. Television signals can be carried over long distances by means of coaxial cable, but very little coaxial cable is so far installed in the United States. There are a few lines between such cities as New York

and Philadelphia, and New York and Chicago, but the branches from those cables are ordinary telephone line. Hence, most theatres within the foreseeable future will have to receive television signals by radio.

TELEVISION FILM PROJECTORS

(8) The television camera may be used to reproduce a motion picture rather than an actual scene. There are some advantages, when instantaneous reproduction is not necessary, in making a motion picture of the scene to be televised and subsequently televising from film.

(9) For this purpose a common photo-electric cell can take the place of the television camera. One type of television motion picture projector operates without an intermittent movement and without a shutter. A large disc with a ring of small holes near its outer edge rotates in the path of the light. As one hole sweeps across the aperture it scans one "line" of the picture horizontally, the light passing through that hole being focussed upon the photo-cell. By the time the next succeeding hole scans the picture the film has moved downward slightly, thus a lower "line" of the picture is scanned. There is no need for an intermittent movement and there is no need for a shutter. In order to obtain 30-frame scanning the speed of the projector motor is increased to provide a rate of film motion of 30 frames a second.

(10) Other devices for using motion picture film in association with television equipment include a projector without an intermittent movement but fitted with a rocking mirror which receives the light from the aperture and focuses it through a lens on a stationary mirror. A television camera in turn is focussed upon the stationary mirror.

(11) There is also a type of television projector using a modified old style Powers movement. The modification consists in the fact that the pull-down occurs at unequal intervals. Alternate frames remain stationary 1/20th second and 1/30th second, respectively. Alternately the cam rotates 144° and 216° before the next pull-down occurs. The over-all film speed is standard.

The shutter has only one opening, and the frame that remains in the aperture 1/30th second is exposed twice, while the frame that remains in the aperture 1/20th second is exposed three times. The light passing through the shutter is focussed upon a television camera. Either filament type projection lamps or small arc lamps of the kind used for portable 35 mm equipment provide the light.

SOUND TROUBLE-SHOOTING CHARTS

TROUBLE-SHOOTING CHARTS

We herewith present nineteen charts, constructed as an aid in efficient and speedy location of sound system troubles encountered by projectionists in their work. In somewhat different form these charts originally appeared over a period of eleven months in the Better Theatres section of the Motion Picture Herald. As here presented they must be considered in connection with variations in the constructional detail of equipments, conditions encountered in different projection rooms, and in individual instances of trouble itself. Conditions vary so often and so widely that no fixed set of rules can possibly be applied inflexibly to all sound troubles encountered by projectionists. These charts must be tempered by an application of common sense, as is necessary in the case of almost every rule evolved by mankind since the time of Adam.

The charts may be used in either of two different ways. First, applied exactly as they appear they will be found very helpful in systematizing search for average troubles in average sound systems or equipments. Second, their use will, however, be enormously increased if they are considered as models by which the projectionist may construct similar charts modified to fit more closely the exact conditions peculiar to his own equipment, installation and projection room. Here is a point of high value: In the act of drawing up such modifications the projectionist will experience what amounts to an advance rehearsal of practically every job of trouble-shooting that he will ever be likely to encounter in practice. When trouble arrives he will then need only refer to his charts to refresh his memory of the correct procedure by which it may be located and remedied with the least possible waste in either time, effort or labor.

Even though the charts be used as hereinafter presented, without modification, the projectionist should find his work in locating and remedying trouble to go forward much more smoothly and with increased speed, as compared with working without them. The tests listed have been very carefully arranged in the most logical order of procedure. Those that are most easy to apply, or that are the most likely to discover the seat of the trouble, appear first. Those tests that involve difficulty in application, or that offer less promise of producing the desired answer, are not listed until the first group have failed to yield definite results.

Further, all tests are arranged in a sequence of elimination designed to draw an ever narrowing circle around the real seat of the trouble, until the point is finally reached where only one other cause for the difficulty should be theoretically possible. The charts then prescribe the final test, with "Trouble Found" written after it.

However, theatre sound systems vary greatly and there is always possibility certain exceptional types of trouble, or individual peculiarities of apparatus or installations in which the logical sequence of elimination, as represented by the charts, fails to work. That is an outstanding reason why these charts should, wherever possible, be modified in advance to suit individual conditions. Such modification should of course be made to follow the same procedure of logical order and of systematic sequence of elimination.

IMPORTANT: Certain charts have notes of warning or caution, which same should be carefully considered before using the chart involved, since they relate to protection of both equipment and workmen. Modern sound systems employ voltages capable of inflicting serious or even fatal injury unless proper precautions be taken in their handling. Then, too, when the charts indicate necessity for replacement of some part of the equipment, the notes may also indicate desirability of checking the voltage to which the new part will be exposed. Failure in this respect may result in early or even immediate ruin of the new part.

APPLICATION: To use the charts, begin at the upper left hand corner with the first test prescribed. All the normally possible results of that test are listed in the central column, the right hand column indicating what should be done in each case.

For example: Test No. 1, chart No. 1, prescribes checking certain easily visible indications of trouble. The central column indicates that one result may be that everything is found to be normal, in which case the right hand column advises proceeding to test No. 2. However, the central column lists other possible results of test No. 1. Thus, if a meter shows faulty reading, the right hand column advises test No. 34, which test, in its turn, calls for investigation of the cause for the faulty reading, in accordance with whichever one of the other charts covers that item of apparatus the operation of which the meter in question records. Assuming the meter to be installed in a sound power supply rectifier, and that chart No. 4 applies, the procedure just traced must be followed to that chart, beginning with test No. 1 in its left hand column, checking through to central and right hand columns, proceeding in each case in accordance with what the right hand column indicates.

Under all save exceptional conditions, following this procedure from step to step should prove to be the most rapid, methodical and efficient method of locating and remedying sound troubles.

1.

To Determine the Cause and Correction of NO SOUND, FAULT LOCATION UNKNOWN

NOTE: Because of the wide variety of monitoring circuits used today, this chart does not provide for faster trouble-shooting by comparing monitor speaker output with stage speaker output. Such provisions, suited to individual projection room conditions, may profitably be added by the reader.

THE TROUBLE TESTS	THE CONDITION FOUND	NEXT TEST
1. Check all signal lamps, switch positions, exciter and tube filaments, and all meter positions that can be observed without delay or switching	All indications normal	No. 2
	Signal lamp not lighted	No. 35
	Switch in wrong position	No. 36
	Exciter or tube not lighted	No. 37
	Meter reading wrong	No. 34
2. Change to emergency channel	No emergency channel	No. 3
	Sound restored	No. 26
	No sound either channel	No. 28
3. Read all permanently installed meters	All readings normal	No. 4
	Meter reading abnormal	No. 34
4. Change to (or make click test on) other projector	Sound from other projector normal	No. 5
	No sound, either projector	No. 10
5. Run on good projector; check faulty projector output with headphones	Sound heard in headphones	No. 6
	No sound heard in phones	No. 8
	Level at head output too low for phones	No. 9
6. Beginning with terminals at both ends, check line from head output to changeover switch, using ohm meter	TROUBLE FOUND	
	No trouble found	No. 7
7. Check projector changeover switch for faulty operation, dirty contact, open or short	TROUBLE FOUND	
8. Proceed per Chart No. 8	TROUBLE FOUND	
9. Proceed (in order given) per Tests 6, 7 and 8, above	TROUBLE FOUND	
10. Check with headphones at output line to speakers	Sound heard	No. 11
	No sound heard	No. 14
11. Check speaker field excitation	Excitation normal	No. 12
	Excitation low or zero	No. 13

THE TROUBLE TESTS	THE CONDITION FOUND	NEXT TEST
●	●	●
12. Proceed per Chart No. 18	TROUBLE FOUND	
13. Check field excitation source per Charts Nos. 4, 5 or 11	TROUBLE FOUND	
14. Check projector changeover switch for faulty operation, dirty contact, etc.	TROUBLE FOUND	
	No trouble found	No. 15
15. Check filter network output and input with headphones	No filter network	No. 19
	No sound heard, input or output	No. 19
	Sound heard, input not output	No. 16
	Sound heard, input and output	No. 18
16. Check filter network output line for short	TROUBLE FOUND	
	No short found	No. 17
17. Investigate filter network for internal open or short	TROUBLE FOUND	
18. Check line from network output to output terminals leading to speakers	TROUBLE FOUND	
19. Check with headphones between voltage and power amplifiers	Voltage and power amplifier one unit	No. 20
	No sound heard	No. 22
	Sound heard	No. 21
20. Proceed per Chart No. 14	TROUBLE FOUND	
21. Check power amplifier per Test No. 20, above	TROUBLE FOUND	
22. Check with headphones at voltage amplifier input terminals	Sound heard	No. 23
	No sound heard	No. 24
	Level at voltage amplifier input terminals too low for headphones	No. 25
23. Check voltage amplifier per Test No. 20, above	TROUBLE FOUND	
24. Beginning at both sets of terminals, check line from projector changeover to voltage amplifier input, including non-synch input switch if any	TROUBLE FOUND	
25. Proceed (in order given) per tests 24 and 23, above	TROUBLE FOUND	

THE TROUBLE TESTS	THE CONDITION FOUND	NEXT TEST
26. Inspect regular-emergency switch for faulty, dirty, loose or open contacts	TROUBLE FOUND	
	Trouble not found	No. 27
27. Check faulty channel amplifiers per Test No. 20, above. (If this can be done between or after shows, save effort by first using Test No. 19, above, to isolate faulty amplifier unit)	TROUBLE FOUND	
28. Change to, or make click test on, other projector.	Sound from other projector normal	No. 5
	No sound, either projector	No. 29
29. Check with headphones at output to loud speakers	Sound heard	No. 11
	No sound heard	No. 30
30. Try sound from non-synch source (or rap first voltage amplifier tube with fingernail or shake it in socket; being sure to choose the channel switched into service)	Sound heard	No. 31
	No sound heard	No. 33
31. Check projector changeover switch for faulty operation, dirty contact, open or short connection	TROUBLE FOUND	
	No fault found	No. 32
32. Proceed (in order given) per Tests 26 and 24, above	TROUBLE FOUND	
33. Proceed (in order given) per Tests 26, and 15, above	TROUBLE FOUND	
34. Investigate unit showing faulty meter reading per Charts Nos. 4, 5, 7, 8, 9, 11, 13 or 14	TROUBLE FOUND	
35. Investigate (in order named) switches, fuses, circuit associated with unlighted lamp	TROUBLE FOUND	
36. Switch to proper position	TROUBLE CURED	
37. Check unit carrying unlighted exciter or tube per Test No. 34, above	TROUBLE FOUND	

2.

To Determine the Cause and Correction of LOW VOLUME, FAULT LOCATION UNKNOWN

NOTE: Because of the wide variety of monitoring circuits used today, this chart does not provide for faster trouble-shooting by comparing monitor speaker output with stage speaker output. Such provisions, suited to individual projection room conditions, may profitably be added by the reader.

THE TROUBLE TESTS	THE CONDITION FOUND	NEXT TEST
1. Observe volume control settings	All control settings normal	No. 2
	One control setting low	No. 17
2. Check reverse feedback settings	All settings normal	No. 3
	One or more settings low	No. 17
	No reverse feedback adjustments	No. 3
3. Observe all tube filaments	All filaments normal	No. 4
	One filament not lighted	No. 18
	One or more filaments dim	No. 18
4. Observe readings, all installed meters	All readings normal	No. 5
	One or more readings low	No. 19
5. Observe all exciter filaments	Exciter filaments normal	No. 6
	One or more filaments dim	No. 20
6. Check volume of emergency	Emergency volume normal	No. 26
	Emergency volume low	No. 27
	No emergency channel	No. 7
7. Check speaker field excitation	Field excitation normal	No. 8
	Field excitation low	No. 32
8. Check volume of other projector	Other projector normal	No. 35
	Other projector volume low	No. 9
9. Using test meter, read all photo-cell and tube socket voltages	One or more voltages low	No. 37
	All voltages normal	No. 10
10. Check all sound circuit switches for faulty or dirty contact; check rotary controls for loose knob or shaft giving false indication	All contacts normal	No. 11
	TROUBLE FOUND	
11. Using headphones, check volume at all external sound connections from sound changeover to speakers, to isolate faulty unit	Amplifier found faulty	No. 13
	Filter network found faulty	No. 14
	Volume levels cannot be estimated	No. 12
	Fault isolated to backstage circuits	No. 38

THE TROUBLE TESTS ●	THE CONDITION FOUND ●	NEXT TEST ●
12. Repeat Test No. 11, above, using constant signal film or oscillator, and volume indicator in place of headphones	Amplifier found faulty	No. 13
	Filter network found faulty	No. 14
	Fault isolated to backstage circuits	No. 38
	Test equipment not available	No. 39
13. Check faulty amplifier per Chart No. 15	TROUBLE CURED	
14. Check faulty section of network circuit visually, manually and with ohm meter	TROUBLE FOUND	
	Fault not found	No. 15
15. Using ohm meter, test resistors and inductors of faulty section of network for open, short or high or low resistance	TROUBLE FOUND	
	Fault not found	No. 16
16. Test or replace condensers in faulty section of network	TROUBLE CURED	
17. Adjust setting	TROUBLE CURED	
18. Check unit showing dim or unlighted filament per Charts Nos. 5, 9, 12 or 15	TROUBLE CURED	
19. Check unit showing low reading per Test No. 18, above	TROUBLE CURED	
20. Replace exciter lamp	TROUBLE CURED	
	Replacement lights dimly	No. 21
21. Check lamp voltage at lamp socket	Voltage normal	No. 22
	Voltage low	No. 23
22. Check socket for loose or dirty contact	TROUBLE FOUND	
23. Check lamp voltage at voltage source, disconnect line to lamp	Voltage normal for open line	No. 24
	Voltage low for open line	No. 25
24. Using ohm meter, check line to lamp, and lamp socket, for high resistance contact or short	TROUBLE FOUND	
25. Check voltage source per Charts Nos. 5 or 12	TROUBLE CURED	
26. Apply Tests No. 9, 10, 11, 12, et seq., to regular channel only	TROUBLE CURED	

THE TROUBLE TESTS ●	THE CONDITION FOUND ●	NEXT TEST ●
27. Check speaker field excitation	Field excitation normal Field excitation low	No. 28 No. 32
28. Check volume from other projector	Other projector volume normal Other projector volume low	No. 35 No. 29
29. Apply Tests No. 11 (or 12), 14, 15 and 16, above, to filter network	TROUBLE FOUND No trouble found No filter network	 No. 30 No. 30
30. Apply tests No. 10, 11 (or 12) and 14, above, to external or internal connections between changeover and amplifier, including changeover	TROUBLE FOUND No trouble found	 No. 31
31. Apply Test No. 30, above, to backstage circuits	TROUBLE FOUND	
32. Check excitation voltage at source, disconnecting line to speakers	Voltage normal for open line Voltage low for open line	No. 33 No. 34
33. Proceed per Test No. 24, above, to clear speaker excitation line	TROUBLE CURED	
34. Apply Test No. 25, above	TROUBLE CURED	
35. Proceed per Chart No. 9	TROUBLE FOUND Trouble not found	 No. 36
36. Apply Test No. 30, above, to circuits between faulty projector and sound changeover	TROUBLE FOUND	
37. Apply Test No. 18, above, to unit showing faulty reading	TROUBLE FOUND	
38. Apply Test No. 31, above	TROUBLE FOUND	
39. Apply Test No. 13, above, to all amplifiers, except those associated exclusively with one projector only	TROUBLE FOUND No trouble found	 No. 40
40. Apply Tests No. 14, 15 and 16, above, to filter network	TROUBLE FOUND No trouble found No filter network	 No. 41 No. 41
41. Apply Test No. 14, above, to all *external* sound lines	TROUBLE FOUND No trouble found	 No. 42
42. Apply Test No. 31, above	TROUBLE FOUND	

3.

To Determine the Cause and Correction of DISTORTION, FAULT LOCATION UNKNOWN

THE TROUBLE TESTS	THE CONDITION FOUND	NEXT TEST
1. Check all installed meters, all signal lamps, brightness of all filaments (including exciter) and all switch and control settings	All indications normal	No. 4
	Meter reading wrong	No. 2
	Tube filament too bright (or too dim)	No. 2
	Exciter filament too bright or too dim	No. 5
	Signal lamp indication wrong	No. 3
	Control setting found incorrect	No. 3
2. Check faulty unit per Charts Nos. 10, 13, 17 or 19	TROUBLE FOUND	
3. Correct faulty setting	TROUBLE CURED	
4. Check if distortion is present with other projector working	Distortion in one projector only	No. 5
	Distortion same, either projector	No. 6
5. Proceed per Chart No. 10	TROUBLE FOUND	
6. Listen to determine if distortion is type attributable to improper volume distribution between h.f. and l.f. speakers	L.f.-h.f. volume distribution faulty	No. 7
	L.f.-h.f. volume distribution not involved	No. 10
	No separate l.f.-h.f. speaker systems	No. 10
7. Check field excitation to l.f. and h.f. speaker banks	Field excitation values wrong	No. 8
	No fault, field excitation	No. 9
8. Check field supply rectifier per Charts Nos. 4, 5 or 12	TROUBLE CURED	
9. Using ohm meter, check l.f.-h.f. filter network wiring and parts, changing condensers if condenser tester is not available	TROUBLE FOUND	
	No fault in filter network	No. 10
10. Using headphones, check sound at output of each amplifier	Faulty amplifier located	No. 11
	No fault in amplifying system	No. 12
11. Proceed per Chart No. 17	TROUBLE FOUND	
12. Proceed per Chart No. 19	TROUBLE FOUND	

4.

To Determine the Cause and Correction of NO POWER OUTPUT FROM RECTIFIER

NOTE A: Whenever steps 5, 7, 12, 14 or 17 prove necessary, check for high line voltage as possibly being the basic cause of the difficulty.

NOTE B: Whenever steps 5 or 17 prove necessary, fuse the new transformer temporarily (if permanent fusing is not provided) to protect it in case an undiscovered short circuit still remains.

THE TROUBLE TESTS ●	THE CONDITION FOUND ●	NEXT TEST ●
1. Inspect tubes	Tubes lit Tubes out Tubes lit, no blue glow (gas tubes only)	Test No. 2 Test No. 12 Test No. 2
2. Inspect plate circuit fuses	Fuses good Fuses out No plate circuit fuses	Test No. 3 Test No. 7 Test No. 3
3. Check plate transformer voltages	No input or output voltage Input voltage normal, no output voltage Voltages normal	Test No. 4 Test No. 5 Test No. 6
4. Check for open between transformer and power source	TROUBLE FOUND	
5. Replace plate transformer	TROUBLE CURED	
6. Check for open between transformer and rectifier output	TROUBLE FOUND	
7. Replace burnt out fuse	Fuse doesn't hold TROUBLE CURED	Test No. 8
8. Disconnect load, again replace fuse	Fuse holds Fuse doesn't hold	Test No. 9 Test No. 10
9. Check load and connecting lines for short circuit	TROUBLE FOUND	
10. Open power switch, discharge all condensers with insulated screw driver, feel all parts for over-heating, sign of short circuit	TROUBLE FOUND No short circuit found	Test No. 11
11. Check or replace condensers one by one	TROUBLE CURED	

THE TROUBLE TESTS ●	THE CONDITION FOUND ●	NEXT TEST ●
12. Replace tubes	TROUBLE CURED	
	New tubes won't light	Test No. 13
	New tubes burn out	Test No. 17
13. Check filament or line fuse	Fuse out	Test No. 14
	Fuse good	Test No. 16
14.. Replace fuse	TROUBLE CURED	
	Fuse won't hold	Test No. 15
15. Check between fuse and tube filaments for short circuit	TROUBLE CURED	
16. Check between fuse and tube filaments for open circuit	TROUBLE CURED	
17. Replace filament transformer	TROUBLE CURED	

5.

To Determine the Cause and Correction of LOW OUTPUT FROM RECTIFIER

THE TROUBLE TESTS ●	THE CONDITION FOUND ●	NEXT TEST ●
1. Check line voltage	Line voltage low	Test No. 2
	Line voltage normal	Test No. 3
2. Adjust line voltage regulator	TROUBLE CURED	
3. Replace tubes	TROUBLE CURED	
	Output remains weak	Test No. 4
4. Inspect condenser fuses	All condenser fuses good, or no fuses	Test No. 7
	One condenser fuse open	Test No. 5
5. Replace open fuse	TROUBLE CURED	
	New fuse won't hold	Test No. 6
6. Replace associated condenser	TROUBLE CURED	
7. Inspect output voltage regulators for misadjustment, open or short	TROUBLE FOUND	
	Output voltage regulators normal	Test No. 8
8. Check filament transformer voltages	Input voltage low	Test No. 14
	Output voltage low, input normal	Test No. 13
	Voltages normal	Test No. 9
9. Check plate transformer voltages	Input voltage low	Test No. 12
	Output voltage low, input normal	Test No. 11
	Voltages normal	Test No. 10
10. Check condensers and bleeders for open circuit	TROUBLE FOUND	
11. Replace plate transformer	TROUBLE CURED	
12. Check for dirty power switch or other high resistance between power source and transformer	TROUBLE FOUND	
13. Replace filament transformer	TROUBLE CURED	
14. Check filament transformer per Test 12	TROUBLE FOUND	

6.

To Determine the Cause and Correction of HUM, ORIGINATING AT THE RECTIFIER

THE TROUBLE TESTS ●	THE CONDITION FOUND ●	NEXT TEST ●
1. Install new tubes	TROUBLE CURED Hum remains	 Test No. 2
2. Inspect output fuses for high resistance fuse or dirty contact	TROUBLE FOUND All output fuses normal	 Test No. 3
3. Inspect condenser fuses	All condenser fuses normal One condenser fuse open One condenser fuse high resistance No condenser fuses	Test No. 7 Test No. 5 Test No. 4 Test No. 7
4. Replace defective fuse	TROUBLE CURED	
5. Replace open fuse	TROUBLE CURED New fuse won't hold	 Test No. 6
6. Replace associated condenser	TROUBLE CURED	
7. Check all condensers and associated wiring for open circuit	TROUBLE FOUND Condensers and wiring normal	 Test No. 8
8. Clean and tighten all external grounds	TROUBLE CURED. If hum remains—	Test No. 9
9. Remove external ground connections one at a time	TROUBLE CURED. If hum remains—	Test No. 10
10. Tighten holding bolts of all transformers and choke coils	TROUBLE CURED. If hum remains—	Test No. 11
11. Check for grounded output voltage control resistor	TROUBLE CURED. If hum remains—	Test No. 12
12. Check for shorted or grounded choke coil	TROUBLE FOUND	

7.

To Determine the Cause and Correction of HIGH VOLTAGE OUTPUT FROM RECTIFIER

THE TROUBLE TESTS ●	THE CONDITION FOUND ●	NEXT TEST ●
1. Check line voltage	Line voltage low	Test No. 2
	Line voltage normal	Test No. 3
2. Adjust line voltage regulator	TROUBLE CURED	
3. Inspect condenser fuses	All condenser fuses normal	Test No. 6
	One condenser fuse open	Test No. 4
	No condenser fuses	Test No. 6
4. Replace open fuse	TROUBLE CURED	
	New fuse won't hold	Test No. 5
5. Replace associated condenser	TROUBLE CURED	
6. Check all condensers, bleeders and their wiring for open circuit	TROUBLE FOUND	
	Condensers, bleeders and wiring normal	Test No. 7
7. Check series chokes and resistors for short or ground	TROUBLE FOUND	

8

To Determine the Cause and Correction of NO SOUND, DUE TO HEAD TROUBLE

THE TROUBLE TESTS	THE CONDITION FOUND	NEXT TEST
1. Observe exciter lamp	Lamp lit normally Lamp out Lamp dim	No. 2 No. 16 No. 21
2. Observe if light reaches p.e.c.	Light path normal Light path obstructed	No. 3 No. 15
3. Wave finger or pencil in light path (move film out of way)	Normal clicking No sound heard	No. 4 No. 5
4. Re-thread film, making sure sound track is correctly aligned	TROUBLE CURED	
5. Check p.e.c. voltage with very high resistance meter, or ahead of p.e.c. load resistor with low resistance voltmeter	No p.e.c. voltage P.e.c. voltage normal P.e.c. voltage low	No. 6 No. 10 No. 6
6. Check voltage at output of p.e.c. supply unit	Output voltage normal No output voltage Output voltage low	No. 7 No. 8 No. 9
7. Check line between supply unit output and p.e.c. for open or short	TROUBLE FOUND	
8. Check supply unit failure per Chart No. 4 or No. 11 according to voltage supply used.	TROUBLE FOUND	
9. Check supply unit failure per Chart No. 5 or No. 12 according to voltage supply used.	TROUBLE FOUND	
10. Replace p.e.c.	TROUBLE CURED No sound	 No. 11
11. Using high resistance ohm meter check p.e.c. output circuits, load resistor, transformer, etc., for open, ground or short; check p.e.c. amplifier (if any) per Chart No. 14.	TROUBLE FOUND No trouble found	 No. 12

THE TROUBLE TESTS	THE CONDITION FOUND	NEXT TEST
12. Switch off stage speakers (if audience present) and temporarily open high resistance circuits between p.e.c. output and head output, listen for squeal in monitor speaker	Squeal heard No squeal heard	No. 13 No. 14
13. By visual inspection, ohm meter, tugging wires and replacement of parts if necessary, check between point where open circuit caused squeal and p.e.c.	TROUBLE FOUND	
14. By visual inspection, ohm meter, tugging wires and replacement of parts if necessary, check between p.e.c. output and head output	TROUBLE FOUND	
15. Clear obstruction, re-thread	TROUBLE CURED	
16. Replace exciter lamp	TROUBLE CURED New lamp does not light New lamp burns out	 No. 17 No. 20
17. Check output voltage, exciter lamp supply unit	No output voltage Output voltage normal	No. 18 No. 19
18. Check exciter lamp supply unit per Chart No. 4.	TROUBLE FOUND	
19. Check line between exciter lamp supply unit and exciter lamp for open, short or ground	TROUBLE FOUND	
20. Check exciter lamp supply unit per Chart No. 7.	TROUBLE FOUND	
21. Replace exciter lamp	TROUBLE CURED New lamp lights dim	 No. 22
22. Check output voltage, exciter lamp supply unit	Voltage low Voltage normal	No. 23 No. 24
23. Check exciter lamp supply unit per Chart No. 5.	TROUBLE FOUND	
24. Check line between exciter lamp supply unit and exciter lamp for partial short or ground, or high resistance contact	TROUBLE FOUND	

9

To Determine the Cause and Correction of LOW VOLUME, DUE TO HEAD TROUBLE

THE TROUBLE TESTS	THE CONDITION FOUND	NEXT TEST
1. Observe color of exciting light at film or p.e.c. location	Light white Light yellow	No. 2 No. 12
2. Check exciting light focus	Focus correct Focus poor	No. 3 No. 8
3. Check p.e.c. voltage with very high resistance meter, or ahead of p.e.c. load resistor with low resistance meter	Voltage normal Voltage low	No. 4 No. 7
4. Replace p.e.c.	TROUBLE CURED Volume still low	 No. 5
5. Using high resistance ohm meter check p.e.c. output circuits, load resistor, transformer, etc., for partial ground or short	TROUBLE FOUND No trouble found	 No. 6
6. By visual inspection, ohm meter, tugging wires and replacement of parts if necessary, check between p.e.c. output and head output	TROUBLE FOUND	
7. Proceed per Trouble Test No. 6 of Chart No. 8.	TROUBLE FOUND	
8. Adjust focus	TROUBLE CURED Good focus unobtainable	 No. 9
9. With spotlight gelatine and magnifier inspect exciter lamp filament *while lit* for sag or slope	Filament sags or slopes when hot Filament normal	No. 10 No. 11
10. Replace exciter lamp	TROUBLE CURED	
11. Inspect optical system lens tube, lenses, prism, slit	TROUBLE FOUND	
12. Clean oil from optical lenses, prism, exciter lamp, p.e.c., opening or replacing lens tube if necessary	TROUBLE CURED	

10

To Determine the Cause and Correction of DISTORTION, ORIGINATING AT THE HEAD

THE TROUBLE TESTS	THE CONDITION FOUND	NEXT TEST
1. Check exciting light focus	Focus correct	No. 2
	Focus poor	No. 12
2. Check p.e.c. voltage with very high resistance meter, or ahead of p.e.c. load resistor with low resistance meter	Voltage normal	No. 3
	Voltage high	No. 9
	Voltage low	No. 11
3. Replace p.e.c.	TROUBLE CURED	
	No improvement found	No. 4
4. Make and run a test *loop* of sound print (not frequency film), thus eliminating the take-up action, and listen for distortion	No distortion heard	No. 5
	Distortion remains	No. 6
5. Adjust, lubricate, repair or replace take-up	TROUBLE CURED	
6. Check for and eliminate all other causes for unsteady film motion, small side-sway, etc., interchanging projector heads and mechanical drives of sound heads if necessary	TROUBLE FOUND	
	Trouble not mechanical	No. 7
7. Using high resistance ohm meter check p.e.c. output circuits, load resistor, transformer, etc., for partial short or ground	TROUBLE FOUND	
	No trouble found	No. 8
8. By visual inspection, ohm meter, tugging wires and replacement of parts if necessary, check between p.e.c. output and head output	TROUBLE FOUND	
9. Proceed per Chart No. 7.	TROUBLE CURED	
	Distortion remains	No. 10
10. Replace p.e.c.	TROUBLE CURED	
11. Proceed per LOW OUTPUT chart, page 37, Better Theatres for April 2	TROUBLE CURED	
12. Adjust focus	TROUBLE CURED	
	Good focus unobtainable	No. 13
13. Proceed per Test No. 9 of Chart No. 9.	TROUBLE CURED	

11.

To Determine the Cause and Correction of NO SOUND DUE TO POWER CIRCUIT FAILURE

WARNING: Sound amplifier circuits carrying high voltage are NOT always safe to work on merely because line power has been switched off. The full high voltage may be stored in the filter condensers, which should always be discharged by short-circuiting their terminals with a well-protected conductor (such as a screwdriver with a wooden handle) before anything else is done.

NOTE A: No trouble cure can be considered permanent if the ultimate cause is high line voltage and is permitted to remain. Check line voltage whenever the following tests have become necessary: 7, 10, 11, 15, 16, 17, 18, 20, 21, 22, 24, 27, 28.

NOTE B: Whenever replacements prove necessary per Tests 17, 18, 21 and 27, fuse the replacement part temporarily (if permanent fusing is not provided) to protect it in case an undiscovered short circuit still remains.

THE TROUBLE TESTS ●	THE CONDITION FOUND	NEXT TEST ●
1. Inspect tubes	Tubes lit	No. 2
	Tubes out	No. 6
	Tubes lit, no blue glow (gas tubes only)	No. 2
2. Inspect plate circuit fuses	Fuses good	No. 3
	Fuses out	No. 11
	No plate circuit fuses	No. 3
3. Check amplifier tube plate voltages	No plate voltage, any tube	No. 4
	No plate voltage, some tubes only	No. 16
	Test impracticable because of sparking or overheating with amplifier turned on	No. 29
4. Check plate transformer voltages	No input or output voltage	No. 5
	Input voltage normal, no output voltage	No. 17
	Voltages normal (approximately)	No. 18
5. Check for open between transformer and power source	TROUBLE FOUND	
6. Check filament or line fuse	Fuse out	No. 7
	Fuse good	No. 19
7. Replace fuse	TROUBLE CURED	
	New fuse won't hold	No. 8
8. Remove all tubes from sockets	Fuse now holds	No. 9
	Fuse still does not hold	No. 23

THE TROUBLE TESTS ●	THE CONDITION FOUND ●	NEXT TEST ●
9. Install new set of tubes	TROUBLE CURED (test old set to find faulty one)	
	Fuse does not hold	No. 10
10. Check for high resistance short circuit between transformer secondary and filaments	TROUBLE FOUND	
	No short found	No. 25
11. Replace burnt out fuse	TROUBLE CURED	
	Fuse does not hold	No. 12
12. Remove all amplifying tubes from sockets	Fuse now holds	No. 13
	Fuse still does not hold	No. 27
13. Install new set of amplifying tubes	TROUBLE CURED (test old set to find faulty one)	
	Fuse does not hold	No. 14
14. Remove amplifying tubes, reinstall them one at a time	Fuse will not hold	No. 15
15. Check for short or open circuit in all wiring associated with the tube (or pair of tubes) re-installation of which burns out fuse	TROUBLE FOUND	
16. Check for open or short circuit in plate supply line to tubes without plate voltage	TROUBLE FOUND	
17. Replace plate power transformer	TROUBLE CURED	
18. Check filter chokes, condensers and resistors for open or high resistance short circuit	TROUBLE FOUND	
19. Check filament transformer input and output voltages	No input or output voltage	No. 20
	Input voltage normal, no output voltage	No. 21
	Voltages normal (approximately)	No. 22
20. Check for open between transformer and power source	TROUBLE FOUND	
21. Replace filament transformer	TROUBLE CURED	
22. Check for open circuit between transformer and filaments	TROUBLE FOUND	
23. Disconnect filament transformer primary; replace fuse	Fuse now holds	No. 28
	Fuse still does not hold	No. 24
24. Check for short between transformer and power source	TROUBLE FOUND	

THE TROUBLE TESTS ●	THE CONDITION FOUND ●	NEXT TEST ●
25. Check line voltage	Line voltage high	No. 26
26. Reduce setting of line or amplifier voltage control	TROUBLE CURED	
27. Check filter condensers, resistors and wiring for short circuit	TROUBLE FOUND	
28. Check for short between filament transformer secondary and filaments	TROUBLE FOUND	
	No short found	No. 21
29. Remove all. tubes; switch amplifier on	Sparking or overheating stops	No. 30
	Sparking or overheating continues	No. 31
30. Install new set of tubes	TROUBLE CURED (test old set to find faulty one)	
	Sparking or overheating continues	No. 31
31. Switch amplifier off; check B+ line for short circuit	TROUBLE FOUND	

12

To Determine the Cause and Correction of LOW VOLUME, DUE TO POWER CIRCUIT

THE TROUBLE TESTS	THE CONDITION FOUND	NEXT TEST
1. Check line voltage	Line voltage low	No. 2
	Line voltage normal	No. 3
2. Adjust line voltage regulation	TROUBLE CURED	
3. Replace *rectifying* tubes	TROUBLE CURED (test old set to find faulty tube)	
	Volume remains low	No. 4
4. Check filament transformer voltages	Input voltage low	No. 5
	Output voltage low, input normal	No. 6
	Voltages normal (approximately)	No. 7
5. Check for dirty power switch or other high resistance between power source and transformer input	TROUBLE FOUND	
6. Replace filament transformer	TROUBLE CURED	
7. Check plate transformer voltages	Input voltage low	No. 8
	Output voltage low, input normal	No. 9
	Voltages normal	No. 10
8. Check for dirty power switch or other high resistance between power source and transformer input	TROUBLE FOUND	
9. Replace plate transformer	TROUBLE CURED	
10. Check filter condensers for open circuit	TROUBLE FOUND	
	No open found	No. 11
11. Check filter parts and wiring for high resistance line, short or ground	TROUBLE FOUND	

13

To Determine the Cause and Correction of SOUND DISTORTION, DUE TO EXCESSIVE AMPLIFIER VOLTAGES

THE TROUBLE TESTS ●	THE CONDITION FOUND ●	NEXT TEST ●
1. Check line voltage	Line voltage high Line voltage normal	No. 2 No. 3
2. Adjust line voltage regulation	TROUBLE CURED	
3. Check filament transformer output voltage	Voltage high Voltage normal	No. 4 No. 5
4. Readjust filament transformer primary tap connection	TROUBLE CURED	
5. Check plate transformer output voltage	Voltage high Voltage normal	No. 6 No. 7
6. Readjust plate transformer primary tap connection	TROUBLE CURED	
7. Check filter condensers and bleeders for open circuit	TROUBLE CURED No open found	 No. 8
8. Check filter chokes and series resistors for short circuit	TROUBLE FOUND	

14.

To Determine the Cause and Correction of NO SOUND DUE TO AMPLIFIER FAILURE

NOTE A: If any trouble has involved burning out of a part, even of a fuse, check for high line voltage; if this exists, no repair is permanent until voltage correction has been made.

NOTE B: If replacement is necessary per Test No. 39, do not install the new transformer until all its circuits have been checked to make sure no unsuspected short remains.

WARNING: AMPLIFIER VOLTAGES ARE DANGEROUS. When prescribed tests can be made with the amplifier turned off, bleed off the remaining high voltage charges of the filter condensers with a wooden-handled screwdriver or other well insulated conductor, before any work is done. Where tests must be made with the amplifier turned on, use only test prods and cords insulated for a thousand volts, and handle them carefully.

THE TROUBLE TESTS	THE CONDITION FOUND	NEXT TEST
1. Observe plate current meter	Reading normal	No. 2
	No reading	No. 7
	Very low reading	No. 10
	No plate current meter	No. 12
2. Operate plate current meter switch to take all possible readings	All readings normal	No. 3
	One or more readings zero or very low	No. 14
	No plate current meter switch	No. 12
3. Apply test phones across resistor or transformer load of first amplifying tube	Sound heard	No. 4
	No sound heard	No. 18
	Level at first tube output known to be too low to operate headphones	No. 22
4. Apply test phones across resistor or transformer load of second amplifying tube	Sound heard	No. 5
	No sound heard	No. 20
5. Apply test phones successively across resistor or transformer loads of remaining amplifier tubes	Sound heard on each test	No. 6
	No sound heard on one test	No. 24
6. Investigate output circuit for open or short	TROUBLE FOUND	

THE TROUBLE TESTS	THE CONDITION FOUND	NEXT TEST
7. Observe tube filaments	Tubes lit	No. 8
	Tubes out	No. 31
	One tube out	No. 28
8. Operate plate current meter switch to take all possible readings	No reading, any position	No. 9
	Some readings normal	No. 15
	No plate current meter switch	No. 13
9. Trace trouble according to Chart No. 11.	TROUBLE FOUND	
10. Operate plate current meter switch to take all possible readings	All readings low	No. 11
	Some readings normal	No. 15
	No plate current meter switch	No. 15
11. Trace trouble according to Chart No. 12.	TROUBLE FOUND	
12. Observe tube filaments	Tubes lit	No. 13
	Tubes out	No. 31
	One tube out	No. 34
13. Apply test voltmeter to all amplifier socket plate terminals	No plate voltage, any tube	No. 9
	No plate voltage, some tubes	No. 16
	All plate voltages normal	No. 36
14. Observe tube filaments	All normal	No. 15
	One or more tubes out or dim	No. 34
15. Replace tubes showing low plate readings	TROUBLE CURED	
	New tubes give same results	No. 16
16. Apply test voltmeter to voltage divider, by-pass and B circuits of low-reading tube or tubes	TROUBLE FOUND	No. 17
	Trouble not found	
17. Apply test voltmeter to all grid circuits of low-reading tube or tubes	TROUBLE FOUND	
18. Apply headphones to speech input circuits	TROUBLE FOUND	
	Level at input known to be too low to operate headphones	No. 19

THE TROUBLE TESTS	THE CONDITION FOUND	NEXT TEST
19. Visually and manually check all input connections and insulation; use high resistance voltmeter to test input circuit component parts, disconnecting them temporarily as necessary	TROUBLE FOUND	
20. Apply headphones to second tube speech input circuits	TROUBLE FOUND No trouble found	 No. 21
21. Visually and manually check insulation and connections of second tube input circuits; use high resistance voltmeter to test component parts, disconnecting them temporarily as necessary	TROUBLE FOUND	
22. Apply test phones across resistance or transformer load of second amplifying tube	Sound heard No sound heard	No. 5 No. 23
23. Apply tests No. 19 and No. 21	TROUBLE FOUND	
24. Apply test No. 21 to the input circuit of tube at which sound is lost	TROUBLE FOUND	
25. Apply a.c. voltmeter or test lamp to filament transformer primary winding	Primary voltage normal No primary voltage	No. 26 No. 33
26. Apply a.c. voltmeter or low voltage tester (flash light bulb, exciter lamp, etc.) to filament transformer secondary winding	Secondary voltage normal No secondary voltage	No. 27 No. 39
27. Trace supply line to sockets for break in line	TROUBLE FOUND	

THE TROUBLE TESTS	THE CONDITION FOUND	NEXT TEST
28. Replace tube	TROUBLE CURED	
	New tube burns out with plate flashover	No. 29
	New tube lights, but no sound	No. 2
	New tube burns out, no plate flashover	No. 40
29. Check control grid bias voltage at flashover tube socket, if not derived from cathode resistor	Grid bias zero or low	No. 30
	Grid bias normal	No. 41
	Grid bias derived from cathode resistor	No. 30
30. Apply test No. 21 to grid bias circuits	TROUBLE FOUND	
	No trouble found	No. 41
31. Inspect power line fuse	Fuse out	No. 32
	Fuse good	No. 25
32. Replace fuse	TROUBLE CURED	
	Fuse does not hold	No. 33
	Fuse holds, no sound	No. 13
33. Trace trouble according to Chart No. 11.	TROUBLE FOUND	
34. Replace unlit tube	TROUBLE CURED	
	New tube does not light	No. 35
	New tube lights, but no sound	No. 42
	New tube burns out with plate flashover	No. 29
	New tube burns out, no plate flashover	No. 40
35. Trace filament or heater line from filament transformer to socket.	TROUBLE FOUND	
36. Use test milliameter (or voltmeter across tube load) to check all tubes for normal plate current	All plate currents normal	No. 3
	One or more plate currents low or zero	No. 37
37. Replace tubes showing low current reading	TROUBLE CURED	
	New tubes no improvement	No. 38

THE TROUBLE TESTS ●	THE CONDITION FOUND ●	NEXT TEST ●
38. Apply test 21 to all grid and cathode circuits at low-reading tubes	TROUBLE FOUND	
39. Replace filament transformer	TROUBLE CURED	
40. Check filament transformer and its socket for cause of high heater voltage	TROUBLE FOUND	
41. Check voltage divider and plate supply circuits to faulty tube for cause of high plate voltage	TROUBLE FOUND	
42. Operate plate current meter switch to take all possible readings	Replaced tube reading still low	No. 16
	No plate current meter switch	No. 13
	Replaced tube reading normal	No. 3

15.

To Determine the Cause and Correction of LOW VOLUME, DUE TO AMPLIFIER TROUBLE

THE TROUBLE TESTS	THE CONDITION FOUND	NEXT TEST
1. Observe all tube filaments	All filaments lit	No. 2
	One tube out	No. 14
2. Observe volume control setting	Setting normal	No. 3
	Setting low	No. 17
3. Check if volume control knob is tight on shaft	Knob tight	No. 4
	Knob loose	No. 18
4. Check reverse feedback setting	Setting normal	No. 5
	Setting low	No. 20
	No reverse feedback	No. 5
5. Change all tubes	TROUBLE CURED	
	Low volume continues	No. 6
6. Check all plate voltages at sockets	All voltages normal	No. 7
	All plate voltages low	No. 23
	One or more plate voltages low	No. 24
7. Check all screen voltages at sockets	All screen voltages normal	No. 8
	All screen voltages low	No. 23
	One or more screen voltages low	No. 24
8. Check all grid voltages at sockets (use only very high resistance voltmeter, or figure in current drain of meter used)	All grid voltages normal	No. 9
	All grid voltages high	No. 26
	One or more grid voltages high	No. 28
9. Check all heater (filament) voltages	All heater voltages normal	No. 10
	All heater voltages low	No. 23
	One or more heater voltages low	No. 24
10. Check with high resistance headphones to find stage where volume is lost	Trouble is localized	No. 11
	Trouble cannot be localized	No. 21
11. Visually inspect all connections and insulation in trouble area, tug wires, clean contacts, including tube socket and grid clip contacts	TROUBLE FOUND	
	Trouble not found	No. 12
12. Using ohmmeter, check speech circuit parts in trouble area for internal open, ground, short or partial short	TROUBLE FOUND	
	Trouble not found	No. 13

THE TROUBLE TESTS	THE CONDITION FOUND	NEXT TEST
13. Test speech circuit *electrolytic* condensers in trouble area for loss of capacitance, or replace them if condenser tester is not available	TROUBLE FOUND	
14. Replace faulty tube	TROUBLE CURED	
	New tube does not light	No. 15
	New tube burns out	No. 16
15. Check heater supply circuit to socket in question for open or ground	TROUBLE CURED	
16. Check heater supply circuit to that socket for shorted or grounded resistor	TROUBLE FOUND	
17. Adjust setting	TROUBLE CURED	
18. Check if knob setting and contact setting coincide	Contact not in line with knob	No. 19
	Contact in line with knob	No. 4
19. Reset contact, tighten knob	TROUBLE CURED	
20. Reset feedback control	TROUBLE CURED	
21. Repeat Test No. 10, above, using constant-signal film or oscillator, and wide reading volume indicator in place of headphones	Trouble localized	No. 11
	Necessary test equipment not available	No. 22
22. Apply tests 11, 12 and 13, above, to all *amplifying* circuits	TROUBLE FOUND	
23. Proceed per Chart No. 12.	TROUBLE CURED	
24. Check supply circuit in question for high resistance, short or ground, including faulty insulation	TROUBLE FOUND	
	No trouble found	No. 25
25. Check series resistors of supply circuit in question, using ohmmeter to find increased resistance caused by carbonization or partial short	TROUBLE FOUND	

THE TROUBLE TESTS ●	THE CONDITION FOUND ●	NEXT TEST ●
26. Using ohmmeter, check common grid supply resistor for partial open, or increase in resistance due to carbonization	TROUBLE FOUND No common grid supply resistor	 No. 27
27. Check common grid supply rectifier for high output, per Chart No. 7.	TROUBLE FOUND	
28. Using ohmmeter, investigate grid supply circuit in question for partial open or for carbonized resistor	TROUBLE FOUND	

16.

To Determine the Cause and Correction of HUM ORIGINATING IN AN AMPLIFIER

NOTE: Wherever these charts suggest that tubes or condensers be replaced as a group, it should be remembered that only one of the group is likely to be defective, replacement being made en masse for the sake of quick results. All the discarded parts should be saved and tested one by one at convenience. When the faulty unit is found, the rest can be returned to active stock. However, if the fault is of intermittent nature and cannot be found by subsequent test, it is better to discard all the parts rather than take the chance of a recurrence of the trouble.

WARNING: AMPLIFIERS USING HIGH VOLTAGES ARE DANGEROUS. Whenever the prescribed test allows, line current should be cut off and filter condensers discharged, before work is done on the interior of an amplifier. When the nature of the test requires that the amplifier be in operation, use only well insulated test prods and observe every precaution.

THE TROUBLE TESTS	THE CONDITION FOUND	NEXT TEST
●	●	●
1. Note frequency of hum	Hum of line frequency	No. 2
	Hum not of line frequency	No. 29
2. Clean all tube contacts, particularly grid and grid clip contacts	TROUBLE CURED	
	Hum remains	No. 3
3. Inspect speech line at input terminals for unintended ground to shield	TROUBLE FOUND	
	No trouble found	No. 4
4. Install new set of tubes	TROUBLE CURED	
	Hum remains	No. 5
5. Tighten holding bolts of all transformers and choke coils	TROUBLE CURED	
	Hum remains	No. 6
6. Check amplifier external ground connection	Ground line open	No. 7
	Ground contact loose or dirty	No. 8
	Ground contact perfect	No. 9
7. Repair ground line	TROUBLE CURED	No. 9
	Hum remains	
8. Clean and tighten ground contact	TROUBLE CURED	
	Hum remains	No. 9
9. Using ohmmeter, check speech input line for unintended ground	TROUBLE FOUND	
	Speech input line normal	No. 10
10. Check power input fuses for high resistance fuse or dirty contact	TROUBLE FOUND	
	Hum remains	No. 11
11. Check power line switch for dirty contact	TROUBLE FOUND	
	Hum remains	No. 12

THE TROUBLE TESTS	THE CONDITION FOUND	NEXT TEST
12. Check amplifying tube plate voltages at sockets	Voltages normal	No. 13
	Voltages abnormal	No. 20
13. Check grid bias voltages at amplifying tube sockets	All voltages normal	No. 14
	All voltages abnormal	No. 32
	One or more voltages abnormal	No. 28
14. Using headphones or wide-reading volume indicator, check to find stage where hum originates	Trouble localized	No. 15
	Trouble cannot be localized	No. 25
15. Visually and manually inspect trouble area for accidental grounds (including faulty insulation), loose ground contacts, faulty contacts or misplaced wiring; check or replace decoupling condensers	TROUBLE FOUND	
	Trouble not found	No. 16
16. Replace doubtful sockets in trouble area	TROUBLE CURED	
	Hum remains	No. 17
17. Resolder all contacts in trouble area	TROUBLE CURED	
	Hum remains	No. 18
18. Investigate electrical machinery in and near theatre for newly developed faults	Hum source found	No. 19
	Trouble source not found	No. 20
19. Correct faulty machinery, apply hum filter to it, apply hum filter to amplifier, or change amplifier to another power circuit	TROUBLE CURED	
20. Check filter condensers for open or leakage	TROUBLE FOUND	No. 22
	No trouble found	No. 21
	Condenser tester not available	
21. Replace filter condensers	TROUBLE CURED	
	Hum remains	No. 22
22. Check for grounded output voltage control resistor	TROUBLE FOUND	
	Hum remains	No. 23
23. Check for shorted or grounded choke coil	TROUBLE FOUND	
	Hum remains	No. 24
24. Check all amplifier rectifying circuits for open, grounded or shorted lines, including faulty soldered contacts and defective insulation	TROUBLE FOUND	
25. Apply Tests 20, 22, 23 and 24, above	TROUBLE FOUND	
	Trouble not found	No. 26

THE TROUBLE TESTS	THE CONDITION FOUND	NEXT TEST
26. Apply Tests 18 and 19, above	TROUBLE FOUND Trouble not found	 No. 27
27. Apply Tests 15, 16 and 17, above, to all speech circuits of the amplifier	TROUBLE CURED	
28. Check for open grid circuit to tube or tubes showing improper grid bias	TROUBLE FOUND	
29. Check with headphones or wide-reading volume indicator to find stage where hum originates	Trouble localized Trouble not localized	No. 30 No. 31
30. Check or replace decoupling resistor and condenser of faulty stage	TROUBLE FOUND Hum remains No. 18	
31. Apply Test No. 30, above, to all amplifier stages	TROUBLE FOUND Hum remains No. 18	
32. Check grid bias supply rectifiers per Chart No. 6.	TROUBLE FOUND No grid bias supply rectifier Grid bias supply rectifier normal	No. 33 No. 34
33. Check common grid bias resistor for open or high resistance contact, or for unintended ground	TROUBLE FOUND Common grid bias resistor normal	No. 34
34. Check line from common grid bias source for ground, open, or high resistance contact	TROUBLE FOUND	

17.

To Determine the Cause and Correction of DISTORTION ORIGINATING IN AN AMPLIFIER

WARNING: In applying Tests, 5, 6, 9, 11, 15, 17 and 24, above, and similar tests of the earlier charts referred to, take all precautions against contact with high voltage, using long, well insulated test prods and well insulated test leads.

THE TROUBLE TESTS ●	THE CONDITION FOUND ●	NEXT TEST ●
1. Examine all tube filaments	All filaments normal	No. 3
	One tube not lighted	No. 2
2. Proceed per Test No. 28, Chart No. 14.	TROUBLE CURED	
3. Check plate current meter readings	All readings normal	No. 19
	One reading low	No. 4
	Some readings low	No. 6
	All readings low	No. 7
	One reading high	No. 8
	Some readings high	No. 10
	All readings high	No. 12
	Meter reads some tubes only	No. 13
	No meter	No. 14
4. Replace low reading tube	TROUBLE CURED	
	Distortion and low reading remain	No. 5
5. Check all socket voltages of low reading tube with high resistance voltmeter, and examine faulty circuit for cause of improper voltage	TROUBLE FOUND	
6. Apply Test No. 5, above to low reading tubes, and look for trouble cause in those portions of the faulty supply circuit which are common to all tubes affected	TROUBLE FOUND	
7. Proceed per Chart No. 5 or No. 12.	TROUBLE FOUND	
8. Replace high reading tube	TROUBLE CURED	
	Distortion and high reading remain	No. 9

THE TROUBLE TESTS	THE CONDITION FOUND	NEXT TEST
9. Check socket voltages of high reading tube, beginning with control grid voltage, using high resistance meter, and examine faulty circuit for cause of improper voltage	TROUBLE FOUND	
10. Replace all high-reading tubes	TROUBLE CURED Distortion and high reading remain	 No. 11
11. Apply Test No. 9, above, to high reading tubes, beginning with control grid voltages, and look for trouble cause in those portions of the faulty supply circuit common to all tubes affected		
12. Proceed per Chart No. 7 or No. 13.	TROUBLE FOUND	
13. Take all available readings	All readings normal One or more readings abnormal	No. 14 No. 16
14. Replace all tubes	TROUBLE CURED Distortion remains	 No. 15
15. Check all socket voltages, using high resistance meter	All voltages normal Some voltages abnormal	No. 20 No. 18
16. Replace tubes showing abnormal readings	TROUBLE CURED Distortion and abnormal reading remain	 No. 17
17. Check socket voltages of tubes reading abnormally, and investigate faulty supply circuits common to the tubes affected	TROUBLE FOUND	
18. Look for trouble cause in those portions of the faulty supply line which is common only to the tubes affected	TROUBLE FOUND	
19. Replace all tubes	TROUBLE CURED Distortion remains	 No. 20
20. Check setting and tightness of connections of all adjustable by-pass condensers or other devices in the amplifier for modifying sound quality	Setting wrong Connection faulty All settings and connections okay	No. 21 No. 22 No. 23

THE TROUBLE TESTS ●	THE CONDITION FOUND ●	NEXT TEST ●
21. Correct setting	TROUBLE CURED	
22. Tighten connection	TROUBLE CURED	
23. Check setting and tightness of connections of reverse feedback circuit or harmonic equalizer, if any	Setting wrong	No. 21
	Connection faulty	No. 22
	All settings and connections okay	No. 24
	No reverse feedback or harmonic equalizer	No. 24
24. Using headphones check through successive stages of amplification to find stage at which distortion appears	Faulty stage found	No. 25
	Beginning of distortion cannot be distinguished	No. 29
25. Check with ohm meter, and visually and manually if necessary, all connections and insulation of faulty stage speech circuits, tugging at contacts, etc.	TROUBLE FOUND	
	No trouble found	No. 26
26. Using ohm meter, test all parts carrying speech current in faulty stage	TROUBLE FOUND	
	No trouble found	No. 27
27. Test capacitance of or replace all condensers carrying speech current in faulty stage	TROUBLE CURED	
	Trouble remains	No. 28
28. Replace all speech transformers and choke coils carrying speech current in faulty stage	TROUBLE CURED	
29. Apply Tests 25, 26, 27 and 28 successively to all speech circuits of the amplifier	TROUBLE FOUND	

18

To Determine the Cause and Correction of NO SOUND, DUE TO TROUBLE BACKSTAGE

THE TROUBLE TESTS ●	THE CONDITION FOUND ●	NEXT TEST ●
1. Examine speaker cable plugs	TROUBLE FOUND	
	Plug connections okay	No. 2
	No speaker cable plugs	No. 2
2. Check speaker field fuses	Fuse (or fuses) out	No. 3
	Fuse good	No. 8
3. Replace burnt-out fuse	TROUBLE CURED	
	New fuse does not hold	No. 4
	New fuse holds, no sound	No. 8
4. Using test meter, check speaker field lines for partial or complete short circuit, disconnecting parallel circuits if necessary	Short found	No. 5
	No short found	No. 13
5. Disconnect shorted line from fuse box, run show if possible, disconnect shorted line at speaker terminals and check line and speaker separately for short	Short in speaker unit	No. 6
	Short in speaker cable	No. 15
6. Inspect unit at field input connections for ground to frame	TROUBLE FOUND	
	No trouble found	No. 7
7. Replace unit	TROUBLE CURED	
8. Check field voltage at connection box	Voltage normai (approximately)	No. 9
	Voltage very low or zero	No. 18
9. Using headphones, check speech input at connection box	Speech input normal	No. 10
	No speech input	No. 20
10. Check field voltage at speaker units	Voltage normal (approximately)	No. 11
	No field voltage	No. 22
11. Using headphones, check speech input at speaker unit	Speech input normal	No. 12
	No speech input	No. 23
12. Disconnecting lines, test speaker field and voice circuits for open; repair or replace	TROUBLE CURED	
13. Check field voltage at connection box	Voltage normal	No. 14
	Voltage high	No. 24
14. Replace fuse again, using slightly larger size	TROUBLE CURED	

THE TROUBLE TESTS ●	THE CONDITION FOUND ●	NEXT TEST ●
15. Disconnect cable at plug, test sections separately for short or ground	Short at speaker side Short at connection box side	No. 17 No. 25
16. Disconnect cable at speaker, test cable section and unit separately for short or ground	Short in cable section Short in unit	No. 17 No. 6
17. Inspect cable for break or abrasion, and splice; or replace cable section	TROUBLE CURED	
18. Check voltage at output of field supply rectifier	Voltage normal Voltage low or zero	No. 19 No. 26
19. Check line from rectifier to connection box for open circuit, repair or replace	TROUBLE CURED	
20. Disconnect speech lines to speakers and again headphone check sound at connection box	Sound normal No sound heard	No. 21 No. 29
21. Check voice lines to speakers for short or ground; reconnect good lines and run show if possible; check shorted line by disconnecting at plug or at speaker unit; inspect and repair, or replace, shorted cable section or unit	TROUBLE CURED	
22. Open cable at plug connection and test sections separately for open circuit; repair or replace faulty section	TROUBLE CURED	
23. Repeat test No. 22 with reference to speech lines	TROUBLE CURED	
24. Check field supply rectifier for high voltage output according to Chart No. 7.	TROUBLE FOUND	
25. Inspect shorted section for break or abrasion; repair or replace	TROUBLE CURED	
26. Disconnect load and test rectifier output voltage again	Output voltage normal Voltage low or zero	No. 27 No. 28

THE TROUBLE TESTS ●	THE CONDITION FOUND ●	NEXT TEST ●
27. Leaving load disconnected, open-circuit field line at speaker connection box and test disconnected section for short or ground	TROUBLE FOUND No short or ground	 No. 16
28. Check field supply rectifier for NO POWER OUTPUT or LOW OUTPUT, according to Chart No. 4 or No. 5	TROUBLE FOUND	
29. Check speech line from projection room for short, ground or open	TROUBLE FOUND	

19

To Determine the Cause and Correction of DISTORTION, ORIGINATING AT A SPEAKER

NOTE: If any test from No. 10 to No. 19 cannot be carried out because of the nature of speaker construction or through lack of suitable facilities such as centering shims, a simpler but more expensive remedy is afforded by No. 11.

THE TROUBLE TESTS	THE CONDITION FOUND	NEXT TEST
1. Examine all speaker guy wires, ropes or supporting cables for sympathetic vibration, touching or grasping them and listening for any resulting changes in the distortion	Speaker guy vibrating	No. 2
	No vibration found	No. 3
2. Wrap vibrating guy in rags, ozite or flannel over a fair portion of its length	TROUBLE CURED	
3. Similarly check baffle, horn or trumpet for sympathetic vibration of any part, attachment or mounting fixture	Vibration found	No. 4
	No vibration found	No. 7
4. Thoroughly tighten down vibrating part	TROUBLE CURED	
	Part cannot be tightened	No. 5
5. Wrap or wedge vibrating part to prevent vibration.	TROUBLE CURED	
	Vibration cannot be prevented	No. 6
6. Replace vibrating part	TROUBLE CURED	
7. Check whether speaker unit is tightly mounted to baffle	Mounting tight	No. 9
	Mounting loose	No. 8
8. Tighten unit on baffle	TROUBLE CURED	
9. Examine speaker terminal strip for loose connections	TROUBLE FOUND	
	All connections tight	No. 10
10. Test speaker field coil and hum-bucking coil (if any) with ohm meter for imperfect continuity	Intermittent open or short	No. 11
	No trouble found	No. 12
11. Replace speaker unit	TROUBLE CURED	
12. Test voice coil with ohm meter, simultaneously vibrating diaphragm (if possible) by hand	Intermittent open or short	No. 13
	No trouble found	No. 14
13. Replace voice coil and diaphragm	TROUBLE CURED	

THE TROUBLE TESTS ●	THE CONDITION FOUND ●	NEXT TEST ●
14. Remove speaker unit and open as necessary to examine diaphragm mounting	Diaphragm loose	No. 15
	Diaphragm mounting normal	No. 16
15. Tighten diaphragm, checking centering with proper shims as required	TROUBLE CURED	
	Some distortion remains	No. 16
16. Observe diaphragm appearance	Diaphragm bent	No. 13
	Diaphragm torn	No. 13
	Diaphragm normal	No. 17
17. Using proper shims, check centering of voice coil	Voice coil properly centered	No. 19
	Voice coil off center	No. 18
18. Center voice coil (if it shows no signs of being damaged, or loose on the diaphragm)	TROUBLE CURED	
	Some distortion remains	No. 19
19. Remove diaphragm and inspect voice coil for damage, looseness, etc.	Voice coil damaged or loose	No. 13

20.

To Determine the Cause and Correction of HUM, TROUBLE LOCATION UNKNOWN

THE TROUBLE TESTS	THE CONDITION FOUND	NEXT TEST
1. Listen to hum frequency	Hum is line frequency	No. 3
	Hum is sprocket hole frequency	No. 2
	Hum is dividing line frequency	No. 2
	Hum is other than any of these	No. 22
2. Readjust lateral relations of sound track, excitation light (and of photocell light frame, if any) while listening to hum, preferably in headphones	TROUBLE CURED	
3. Check if present in one projector only	Hum heard with one projector only	No. 4
	Hum heard with either projector	No. 12
4. Check for a.c. light reaching photocell	TROUBLE FOUND	
	Trouble not found	No. 5
5. Check positioning of photocell positive lead	TROUBLE FOUND	
	Trouble not found	No. 6
6. Check ground of coaxial cable (if used)	TROUBLE FOUND	
	Trouble not found	No. 7
7. Check hum level with exciter lighted but no film threaded	Hum unchanged	No. 9
	Hum level increases	No. 8
8. Investigate exciter power source per Chart No. 6	TROUBLE CURED	
9. Check hum with motor not running, but exciter lighted	Hum not heard	No. 10
	Hum unchanged	No. 11
10. Check motor and its circuits for sparking or faulty connection	TROUBLE CURED	
11. Check projector ground	TROUBLE FOUND	

THE TROUBLE TESTS	THE CONDITION FOUND	NEXT TEST
12. Turn off system except output amplifier, listening to output amplifier only	Hum remains Only normal background hum heard	No. 13 No. 16
13. Turn off or disconnect all speaker input, except field input	Hum remains Hum disappears	No. 15 No. 14
14. Check speaker field source per Chart No. 6, or if excitation is from amplifier per Chart No. 16	TROUBLE FOUND	
15. Check output amplifier per Chart No. 16	TROUBLE FOUND	
16. Switch on intermediate amplifier (if any)	Hum appears Only normal background hum No intermediate amplifier	No. 17 No. 18 No. 18
17. Apply Test No. 15, above, to intermediate amplifier	TROUBLE FOUND	
18. Switch on voltage amplifier (if any), leaving sound input switched off	Hum appears No separate voltage amplifier Only normal background hum	No. 19 No. 20 No. 20
19. Apply Test No. 15, above, to voltage amplifier	TROUBLE FOUND	
20. Check system ground thoroughly	TROUBLE FOUND Ground and connections okay	 No. 21
21. Check theatre and immediate neighborhood for power switches and machinery functioning imperfectly; have electric company check power lines for leakage; have fault repaired or filter applied	TROUBLE CURED	
22. Check if present in one projector only	Hum heard with one projector only Hum heard with either projector	No. 23 No. 28
23. Check if heard with arc carbon feed motor not running	Hum stops with arc feed motor Arc feed motor has no effect on hum	No. 25 No. 24

THE TROUBLE TESTS ●	THE CONDITION FOUND ●	NEXT TEST ●
24. Overhaul arc feed motor and connections, filtering if necessary	TROUBLE CURED	
25. Check if heard with projector motor not running	Hum not heard Hum unchanged	No. 26 No. 27
26. Overhaul projector drive motor and circuits	TROUBLE CURED	
27. Check PEC amplifier plate circuit condensers and resistors for breakdown permitting amplifier to oscillate	TROUBLE FOUND	
28. Turn on amplifiers one at a time, beginning with output amplifier, to isolate hum. Leave sound input switched off	Faulty amplifier found Hum not heard	No. 29 No. 30
29. Check faulty amplifier per Chart No. 16	TROUBLE FOUND	
30. Apply Tests No. 20 and 21, above	TROUBLE CURED	

ALPHABETICAL INDEX

A

Aberration, chromatic, 182
  spherical, 185, 210
Acoustics, 422-424
Air-core coils, 83
Alternating current, 28-38
  transmission line, 440-446
Alternation, 28, 32
Ampere, 9, 12
Amplification, 487-531
  Class A, 497
  Class B, 497
  push-pull, 493-494
Amplifier (audio), 95-98, 442-443, 481-482, 485-531
  care of, 516-529
  circuits, 490-531
  intermediate frequency, 643-644
  power supplies, 500-506
  radio, 641-642
  troubles, 516-529
Amplifying tubes, 95-98, 442-443, 485-531
Anode, 90, 486
Armature, 130, 131, 132
  open circuit, 158
  overload, 156, 158
  shaft, 133, 156
  short circuit, 156
  tape, 131-133
Aperture, 291-292, 303-306, 322
  tension, 303-306
Arc, electric, 361, 373
  (see also Lamps, projection)
  striking, 373
  in television, 650, 652
  types of, 364
Atom, 6, 7
  nucleus of, 6

B

Back focus, 185
Baffle, 540-545
Ballast resistors, 78-79, 140-141, 143, 375
Barrel distortion, 181, 197
Batteries, 163-168
  "B," 163
  "C," 163
  dry, 163-164, 450
  storage, 164-168, 455
Bearings (motor-generator), 133, 144, 156, 158
  temperature, 159
Bridge circuit, 118-121, 566-567
Brushes, 132, 142, 149, 150-151, 155, 156

C

Camera, television, 630-631
Capacitance, 31-33, 88
Carbide tip, 395
Carbon, 10, 362, 486
Carbon anodes (in amplifying tubes) 486
Carbons, 361-372
  feed mechanisms, 372-373, 381-382, 383, 395-396, 401-402
  speed of consumption, 384-385
  trims, 370-372
Carbon savers, 368-369
Carrying capacities (of wires) 50, 51
Cathode, 90, 486
Cathode ray tube, 628-630, 631, 645, 648
Cell, dry, 163-164, 450
Cell, photoelectric, 97
Cement, film, 259
Changeover cue, 272, 274
Charge, electrical, 6, 7
  of atom, 7
  of electron, 6
  space charge, 93
Choke coil, 82, 624
Circuits, 16
  A, 91
  amplifier, 485-531, 641-642
  B, 91
  bridge, 118-121, 566-567
  C, 94
  filter, 113-116 434, 437, 641-642
  generator, 134-135
  multiple, 41
  parallel, 41-48
  series, 41-48
  series-parallel, 41, 46-47
  short, 18-19
  shunt, 41
  superheterodyne, 642-643
  switching, 478-481, 529, 532
  three-phase, 103-105
  tracing, 451-454
Coaxial cable, 652
Coil, choke, 82
  armature, 130, 131
  field, 129, 132, 133
Commutator, 130, 131, 132, 142, 143, 149-150, 151-156, 157
  lubricating pad, 152-153
  stone, 152
Component, 36, 37, 434
Compound (generator or motor), 135
Condenser (electrical), 32, 33, 38, 87-89
  circuits, 89
  color code, 88
  electrolytic, 87, 88
  in parallel, 89
  in series, 89
  trimmer (see trimmer condenser)
  variable, 624-628
Condenser, optical, 182, 208, 411-413
Conductivity (electrical), 89-91
  unilateral, 93, 94, 109-123
Conductors, electrical, 10
Conduit, 67, 68
  fittings, 68
  flexible, 68
Conjugate foci, 182, 188-189
Control tracks, 576-582
Correction (of lenses), 183, 189
  (of mirrors), 210
Coupling, amplifier tubes, 491-494
  microphone, 476
  motor-generator, 136
  non-synchronous, 482
  photo-electric cell, 467-468
  sound source, 478-482
Crater, 361, 364, 377, 391, 392
Critical angle, 183
Crossover network (see Network, loudspeaker)
Cue, changeover, 272, 274
Cue, motor, 272-273
Cumulative compounding, 135

Current, electric, 8
  alternating, 28-37
  charging, 17
  direction of flow, 8
  peaks, 52, 53
  space, 487
Cycle, 28, 29

D

Decibel, 470, 576-577, 606
Delta connection, 104
Demodulation, 642, 644
Detector, 642, 643, 644, 645
Diagrams, electrical, 219, 451-454, 508, 525-529, 532, 586, 588
  schematic, 452
  symbols for, 219
  wiring, 452
Differential compounding, 135
Direct current, 8-25
  pulsating, 36
Distortion (of screen image), 232-234
Dowser, 373-374, 385
Drawings, electrical, 219, 451-454, 508, 525-529, 532, 586, 588
  symbols of, 219
Drives (sound), 445-446, 550-574
Drycell, 163-164, 450

E

Echo, 423, 424
Edison system, 99-103
Electrical symbols, 219
Electricity, 5, 6, 8
Electro-magnet, 23
Electrons, 5, 6, 29
Emission (of electrons), 90, 91
  photoelectric, 97
  secondary, 93
Equalizers (generator), 141
Equivalent focus, 183, 199, 331, 332, 350
  measuring, 199, 200
Exciter lamp, 461, 463
  focussing, 470

F

Fader, 478-481
Farad, 31
Feedback, reverse, 514-515
Field coil, motor or generator, 129, 132, 133, 157
  control, 453
  speaker, 538
Film, motion picture, 250-275
  causes of damage to, 253-257
  cement, 259
  cleaning, 271
  dimensions, etc., 250, 254, 274-275, 286
  exchange, 253, 263
  projectionist's responsibility for, 253, 263
  reels, 267
  rewinder, 265-266
  rewinding, 264
  splicing, 257-261
  storage of, in projection room, 261-263
  standard release print, 272, 274-275
  threading, 286
Film Path (through projector), 251, 269-270, 322, 323
Filters, 111-112, 113-116, 434-437, 454-455, 579
  frequency, 434-437, 641-642
  resonant, 435
  tuned, 435
Fire shutter, projector, 323
Flame shield, 383
Flutter, 550, 606
Flux (soldering), 63
Focal length, 183, 189, 193-194, 199, 200
  measuring, 200
Focus (of lenses) *see* lenses
  back, 185
Framing, 290-291
Frequency, 28, 29, 33
  audio, 29
  beat, 643
  carrier, 636, 644
  filters, 434-437, 641-642
  high, 29
  intermediate, 29
  low, 29
  medium, 29
  radio, 29
  scanning, 29
  signal, 29
  sound, 29
  video, 29, 637
  ultra, 29
Fundamental, 420-421
Fuses, 69-72

G

Gate, projector, 291-292
  soundhead, 468
Gauge (wire), 50, 51
  (wire measuring) 52
Gears, projector, 293, 294, 318-319
Generators, 129-159, 451-454
  oscillator, 515, 633-634, 642-643, 646-647
Grid (of tube), 94
  circuit, 488, 501-505
  positive, 564
Ground, 19, 102-103, 104-106, 442
  clamp, 106

H

Harmonic, 420-421
  distortion, 514-515
Heaviside layer, 636
Henry, 83
Horn, 540

I

Idler, 287, 320
Impedance, 30-34
  match, 432, 475
  plate, 92
Incidence, angle of, 181, 214
Inductance, 31, 82
Inductors, 82-84
Inspection forms, 590-591, 614-617
Insulation, electrical, 10, 66
Intermittent movement, 295-301
  cam, 297-298
  star, 297-298
Intermittent sprocket, 288, 299-303
Inverse feedback (*see* feedback, reverse)
Ionization, 90
Ions, 90, 93

J

Jaws, carbon, 374

K

Kinetic scanner, 469, 570, 571

L

Laminations, 83, 86
Lamps, projection, 361-415
  (*see also* Arc, electric)
  arc, 372-402
  filament, 403-415
  high intensity, 375-386
  low intensity, 386-389
  low amperage high intensity, 390-395
  ninety-six cycle A.C., 397-398
  old style D.C., 389
  one kilowatt high intensity, 394-395
Lens assembly, 462, 463, 473
Lenses, action of, 185-189
  bi-convex, 181, 186
  cleaning, 195, 218
  collector, 182, 208, 411-413
  condenser, 182, 208, 411-413
  converging, 182, 208, 411-413
  curvature, 190
  equivalent focus, 183, 199, 200, 331, 332
  focusing, 188, 189
  light loss, 194, 196, 217-218, 316-318
  meniscus, 184, 186
  ordering, 192, 194
  pitting, 207
  plano-convex, 184, 186
  projection, 191, 205, 413-414
  repair of, 192
  treated, 217-218
Lenses and Mirrors, 178-218
"Line" (television) 637
Loop (in film) 287-288, 323-324
Lubrication (of motor-generators), 133, 145-146, 152-153, 158
  lamphouse, 381, 384, 389, 400
  pad (for commutators) 152-153
  projector, 293, 294, 295, 299, 319, 320

M

Magazine, projector, 320, 321
Magnet, arc lamp, 374, 392
Magnetic alloys, 25
Magnetism, 22-25, 30
  residual, 134
Maintenance (of sound equipment) 603-621
Microfarad, 31
Microphones, 475-478
Mirror Guards, 374-375
Mirrors (projection), 209-216, 409-411
  action of, 213-214
  care of, 215-217, 387-388, 400-401
  elliptical, 210
  parabolic, 210
  positioning, 388-389, 411
  spherical, 210
Mixer, 643
Modulation, 535-536
Motion pictures, illusion of, 288-289, 308-309
"Motor boating" (in sound), 472-473
Motor-generators, 136
  (*see also* motors and generators)
  installation, 146-149
  sound power supply, 451
Motors, 135-159
  speed controls, 138, 553, 572-574
  starting cue, 273
  synchronous, 136-137, 552
Mushroom tip, 369, 395

N

Network, loudspeaker, 436-437, 532
Neutral (in Edison system), 100

O

Ohm, 12
Ohm's Law, 10-13
  for a.c., 30-33
Oscillator, 515, 633-634, 642-643
  sawtooth, 646-647
Output meter, 606

P

Parallel circuit, 41-48
Parallel plate feed, 492
Peak currents, 52, 53
  voltages, 52, 53
Pedestal, projector, 284-286
Penciling, 368
Pentrode, 95
Phase, 37-38
Phase inversion, 513, 532
Photoelectric cell, 97, 460-468
  construction, 465
  coupling, 466-468, 478
Pick-up, phonograph, 427, 473-475
  "hill and dale", 475
Pick-up, sound, 441
Pincushion distortion, 197
Plate (of tube) 92
  impedance, 92
Polarity, 13, 14, 28
  reversing switch, 31, 74
Ports, lens, 335-337, 338, 347-349
  observation, 335, 337, 338, 347-349, 351
  stereopticon, 338, 347-349
Potential Difference, 11
Potentiometers, 80-82, 478
Power, electric, 20-21, 38
  supplies, 99-104
Power Factor, 38
Principal axis, 184, 187
Projection angle, 184, 331
Projection Room, 331-351
  exits, 349, 351
Projector, motion picture, 284-325, 402
  spacing, 335, 351
  (*see also* Aperture, Gate, Shutter, Sprocket, etc.)
  in television, 653-654
Pulsating direct current, 36
Push-pull sound tracks, 430, 464-465

R

Radio and Television, 624-654
"Rain", 271, 325
Reactance, 31-34
Reactor, 82
Recording (of sound) 426-430
  hill and dale, 427
Rectification, 93, 94, 109-123
Rectifier, 109-123, 454-457
  commutator, 109, 130, 132
  copper oxide, 116-123
  copper sulphide, 116-123
  full-wave, 111-113
  sound, 454-457
  stack, 116-123
  three-phase, 119-123
  tubes, 93, 94, 110-113

Refraction, 184
  angle of, 181, 214
Relays, 115, 121, 455
Resistance, electrical, 9-11
  temperature effect, 10, 49, 50
Resistors, 77-82
  ballast, 78-79, 140-141, 143
  color code, 79-80
  connections, 42-48
Resonance, 421
  in filters, 435
Resultant, 36, 37
Retard coil, 82
Reverberation, 424
Rewinder, film, 265-266
Rheostats, 80-82
Root, square, 21-22
Rotary converters, 139
Rotary stabilizer, 469, 570, 571

S

Scanning (television) 629, 631
  interlaced, 646
  mechanical, 650-652
Schematic (diagram) 452
  symbols, 219
Screens, projection, 225-245
  aging, 227
  beaded, 226
  cleaning, 235
  location, 238, 240-241
  perforated, 236, 237
  recoating, 244
  sizes, 244
  testing reflection power, 228
Series circuit, 41-48
Series-parallel circuit, 41-48
Series wound (generator or motor) 135
Shirt circuit, 18-19
Shunt circuit, 41
Shunt-wound (generator or motor) 135
Shutter, projector, 292, 307-316
  fire, 323
Shutters, port, 346-347, 350
Slip rings, 130
Slit assembly (*see* Lens Assembly)
Soldering, 61-65, 617-618
Sound, frequencies, 419-420, 422
  nature, 417-419
  pitch, 419-420
  reflection, 423-424
  stereophonic, 576-582
  transmission, 422
  volume, 420, 594-598
Soundtrack, 252, 254, 257, 429-430, 460-468, 577-582
Speaker networks, 436-437
Speakers, 444, 535-547
  poling, 547
Spindling, 367-368
Splicing (film), 257-261
Splicing (wires), 60, 61
Sprocket, 287, 288
  intermittent, 288, 299-303
Square root, 21-22
Stack rectifiers, 116-123
Star connection, 104
Stereophonic sound, 576-582
Strippers, 292-293
Superheterodyne circuit, 642-643
Switches, 72-75
  electro-magnetic, 115, 121
Switchboards (power), 75-77
Symbols, electrical, 219
Synchronizing (television), 631, 637
  impulses, 647

T

Take-up, 288, 289-290, 321
Television and radio, 624-654
Television camera, 630-631
Testing sound components, 618-619
Test reels, 605
Tetrode, 95
Threading (of film) 286, 289
Tone control, 435
Transformers, 84-87, 634
Transmission line; a.c., 432-437, 441-442, 546-547
Travel ghost, 316, 325
Treated lenses, 217-218
Trimmer condensers, 627-628
Triode, 95
Trouble lamps, 340
Trouble (sound), 603-614
Tubes (*see* amplifying tube, cathode ray tube, rectifying tube, etc.)

U

Underwriters, 58
  approval, 58
  code, 59

V

Valves (*see* tubes)
Viewing angles, 231, 236-237
Volt, 7, 12
Voltage, 11
  divider, 45, 46
  drop, 45-48, 147, 480
  peaks, 52, 53
Voltmeter, 605
Volume control (sound) 478, 479, 481, 493, 509
  automatic, 507, 576-582
Volume expansion, 506
Volume indicator (*see* output meter)
Volume (of sound), 420, 594-598

W

Watt, 20, 21
Wave shape, 35
Wire, deterioration, 59
Wire gauge, 50, 51
  for gauging wire, 52
Wire tables, 50, 51
Working distance, 185, 200, 201
  measuring, 200-201
Wows, 551

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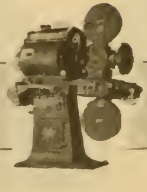

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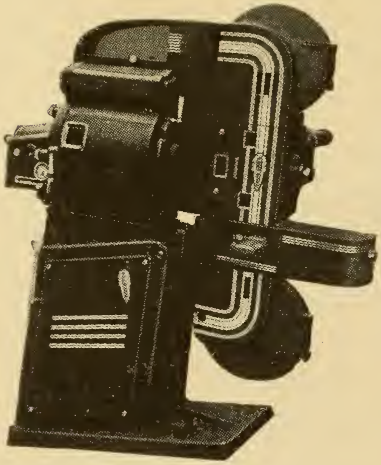

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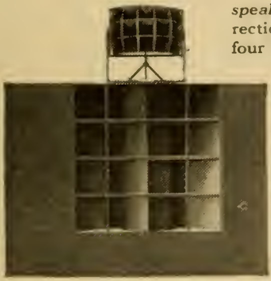

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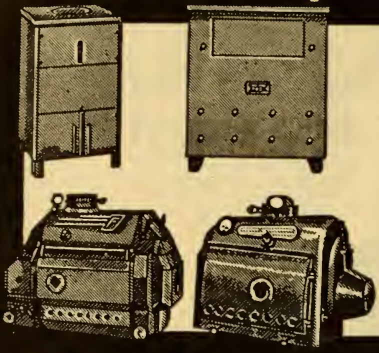

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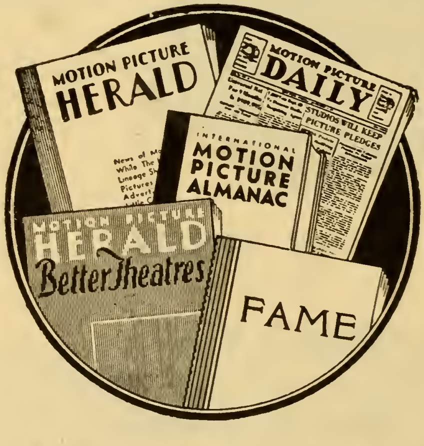

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